

**IMPACT OF RETAIL SALES AND OUTSOURCED MANUFACTURING ON A
BUILD-TO-ORDER SUPPLY CHAIN**

By

Kanay Gupte

B.S. 2003, Electrical Engineering, University of Texas at Austin

Submitted to the MIT Sloan School of Management and the Department of Electrical
Engineering and Computer Science in Partial Fulfillment of the Requirements for the Degrees of

Master of Business Administration

And

Master of Science in Electrical Engineering and Computer Science

In conjunction with the Leaders for Manufacturing Program at the
Massachusetts Institute of Technology

June 2009

© 2009 Massachusetts Institute of Technology. All rights reserved

Signature of Author _____

May 8, 2009

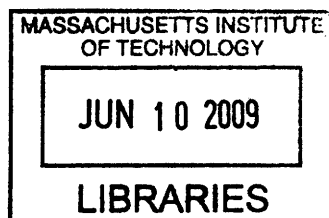
Electrical Engineering and Computer Science
MIT Sloan School of Management

Certified by _____
Chris Caplice, Thesis Supervisor
Executive Director, CTL and MLOG Program, Engineering Systems Division

Certified by _____
Roy Welsch, Thesis Supervisor
Professor of Statistics and Management Science, MIT Sloan School of Management

Accepted by _____
Terry Orlando, Professor of Electrical Engineering and Computer Science
Chair, EECS Committee on Graduate Students

Accepted by _____
Debbie Berechman, Executive Director of MBA Program
MIT Sloan School of Management



ARCHIVES

This page has been intentionally left blank.

IMPACT OF RETAIL SALES AND OUTSOURCED MANUFACTURING ON A BUILD-TO-ORDER SUPPLY CHAIN

By

Kanay Gupte

Submitted to the MIT Sloan School of Management and the Department of Electrical Engineering and Computer Science on May 8, 2009 in partial fulfillment of the requirements for the degrees of Master of Business Administration and Master of Science in Electrical Engineering and Computer Science.

Abstract

Dell Inc. has undertaken a major transformation in strategy since the return of its founder, Michael Dell as company CEO in January 2007. One major aspect of this new strategy is a renewed focus on the consumer market, historically an afterthought compared to Dell's traditional enterprise clientele. In order to more effectively reach consumers around the world, Dell has decided to abandon its direct-only channel strategy and partner with a number of retailers around the world. At the same time, Dell has decided to partner with Contract Manufacturers (CM) and Original Design Manufacturers (ODM) in order to lower manufacturing costs in the extremely competitive consumer market.

Dell's initial entry into Retail and move to some CM/ODM has had both positive and negative effects. Sales volumes have gone up and initial feedback from the retail partners has been encouraging. However, these dramatic changes have exposed some weaknesses in Dell's Build-to-Order supply chain including the demand forecast and capacity planning. The Supply Chain group at Dell would like to understand these unintended effects and adjust the supply chain to mitigate any negative impacts.

The project involves three phases: identifying the challenges of selling PCs through the retail channel and the challenges of outsourcing manufacturing, quantifying the impact of Retail and CM/ODM on Dell manufacturing capacity and offering recommendations for future supply chain design. The results highlight some unexpected outcomes – Dell could require far more manufacturing capacity in the future than originally anticipated based on the initial effects of retail and CM/ODM. The analysis in this thesis suggests that Dell will need to increase order lead-times or decrease daily order variability in retail sales to manage with its current manufacturing capacity. Additionally, Dell will need to minimize the number of different CM/ODM's it partners with in order to benefit from demand pooling and prevent a need for increased manufacturing capacity.

Thesis Supervisor: Chris Caplice

Title: Executive Director, CTL & MLOG Program, Engineering Systems Division

Thesis Supervisor: Roy Welsch

Title: Professor of Statistics & Mgmt Science, MIT Sloan School of Management

This page has been intentionally left blank.

Table of Contents

Abstract	3
Table of Contents	5
List of Figures	7
List of Tables	9
Acknowledgments.....	10
1 Introduction	12
1.1 Statement of Problem.....	12
1.2 Thesis Structure	13
1.3 Company Background	14
1.4 Dell Supply Chain Model	15
2 Current Challenges	17
2.1 Organizational Assessment	17
2.1.1 Three Lens Analysis	17
2.2 Challenge of Selling Through Retail Channel	21
2.2.1 Order Lead Time	24
2.2.2 Sales Variability.....	26
2.3 Challenge of Moving to Outsourced Manufacturing.....	28
2.3.1 Demand Patterns for Notebook Platforms	29
2.3.2 Forecast Accuracy	30
3 Project Methodology and Approach	32
3.1 Definition of Key Concepts.....	33
3.1.1 Definition of Factory Capacity Investment.....	33
3.1.2 Definition of Order Accumulation Time	34
3.2 Data Collection	35
4 Model Functionality and Development.....	39
4.1 Capacity Investment Model	39
4.1.1 Linear Program Formulation	39

4.1.2	Model Features	40
4.1.3	Assumptions	41
4.1.4	Excel Solver Implementation	42
4.1.5	Model Example	43
4.1.6	Model Scenarios	44
4.2	Order Accumulation Time Model	47
4.2.1	Linear Program Formulation	48
4.2.2	Model Features	49
4.2.3	Assumptions	49
4.2.4	Excel Solver Implementation	50
4.2.5	Model Example	51
5	Findings and Discussion	53
5.1	Description of Findings	53
5.1.1	Retail Capacity	53
5.1.2	ODM Capacity	58
5.2	Recommendations	62
5.3	Conclusion	63
	Bibliography	64
	Appendix A Glossary	65

List of Figures

Figure 1: Traditional PC Supply Chain	16
Figure 2: Dell's Build-to-Order Supply Chain	16
Figure 3: Dell Organization Chart.....	19
Figure 4: Typical Retail Buying Cycle	22
Figure 5: Dell Retail Process Map	23
Figure 6: Direct channel order cycle time	25
Figure 7: Retail channel order cycle time	26
Figure 8: Sales Variability – Direct versus Retail Channel	27
Figure 9: Demand for various Notebook Platforms.....	30
Figure 10: Notebook Forecast Accuracy	31
Figure 11: Supply Chain Trade-offs	32
Figure 12: Factory Investment vs. Factory Staffing	34
Figure 13: Definition of Order Accumulation Time	34
Figure 14: Direct and Retail Sales Quarterly Profile	36
Figure 15: Sales Variability – Direct versus Retail Channel	37
Figure 16: Sales Data by Notebook Model and Channel.....	38
Figure 17: Capacity Investment Model Excel Solver Implementation.....	42
Figure 18: Sample Sales Data for Example	43
Figure 19: Capacity Investment Model Example	44
Figure 20: Direct versus Retail Channel Order Variability.....	45
Figure 21: Platform Disaggregation with ODM	46
Figure 22: Order Accumulation Time Model Excel Solver Implementation	50
Figure 23: Order Accumulation Time Model Example.....	52
Figure 24: Direct Channel Sample Results for Required Capacity Investment	54
Figure 25: Retail Channel Sample Results for Required Capacity Investment	54
Figure 26: Direct vs. Retail Channel Capacity Investment	56
Figure 27: Direct versus Retail Order Accumulation Time	58

Figure 28: Capacity Investment with Demand Disaggregation in ODM	59
Figure 29: Capacity Requirements with Demand Disaggregation in ODM	60
Figure 30: Forecast Accuracy with Demand Disaggregation in ODM	61

List of Tables

Table 1: Dell Global Consumer Sales..... 15

Table 2: Weekly Lows and Highs as % of Average Weekly Demand 28

Table 3: Sample Notebook Sales Data 47

Table 4: Sample Notebook Platform Sales Data..... 47

Table 5: Direct vs. Retail Channel Capacity Requirements 55

Table 6: Direct versus Retail Order Accumulation Time 57

Acknowledgments

I would like to thank Dell, especially my internship supervisor Jerry Becker and my project sponsor Annette Clayton, for sponsoring this internship. Jerry and Annette were extremely supportive throughout the project and allowed me the opportunity to define and scope the project and develop the resulting capacity model.

There are many others at Dell that I would like to recognize: Jennifer Felch, Dee Ackermann, OW Craddock, Silpa Sigireddy, Juan Brooks, Hugo Meza, Julie Sher, Shayne Myhand, Allison Searcy, Katie Newman, Lauren Wang, Neil Patwardhan, Brooke Garrett, Ligia Ferreira, Kenny Coleman, Sumit Singh, Jason Kendrick, Jennifer Leandra, Erik Day, Robert Langford, Rajiv Narang, Michael Burke, Scott Gude, Daniel Hernandez, Brian Feller and Sean Trainor. Each of these individuals willingly offered their time, support, and expertise to the project.

I would like to thank my thesis advisors, Roy Welsch and Chris Caplice. Both were invaluable throughout the project, helping me scope the project, providing subject matter expertise and giving me invaluable feedback.

Finally, I would like to thank my wife Kanchan and my entire family for their support during my two year journey at MIT.

This page has been intentionally left blank.

1 Introduction

1.1 Statement of Problem

Market conditions, competition and changing customer needs often force companies to reexamine their business strategies. Often, changing business strategies require changing supply chain strategies to ensure success. Dell Inc. has recently undertaken a major shift in business strategy and the Global Operations team at Dell is examining how best to adjust Dell's supply chain to meet these new business needs. A renewed focus on the consumer PC market has led Dell to partner with major retailers across the globe, abandoning its famed direct-only channel strategy. This has placed new requirements on Dell's supply chain and could have a major impact on future factory investment decisions. Another proposed change is the transition from Dell-owned factories to more Contract Manufacturers (CM) and Original Design Manufacturers (ODM). This transition has the potential to lower overall costs, but could require Dell to adjust its current supply chain strategy. This project will focus on the effect of these two changes on one aspect of the supply chain – manufacturing capacity and investment. Dell Global Operations would like to understand the implications of these two changes on future factory capacity needs. Details of the two aspects to be examined are:

1. Dell's entry into the Retail Sales Channel. Dell has recently partnered with three major retailers in the US (Wal-Mart, Best Buy, Staples) and is considering ways to increase its footprint in retail. The retail channel brings new challenges for Dell's build-to-order supply chain, with extremely large order sizes and other special requirements. This thesis will examine sales in both the retail and direct channels in the US and quantify the factory lead-time needed to handle retail orders without additional capacity investment. The analysis will be used to highlight the effects of sales variability and ultimately guide decisions on designing an efficient retail supply chain.

2. Dell's transition from Dell-owned factories to more Contract Manufacturers (CM/ODM) and Original Design Manufacturers (ODM). This thesis will examine the impact of manufacturing different PC platforms (models) in separate factories as well as potential changes to manufacturing lead-times.

Recommendations will be made regarding design of Dell's future Supply Chain based on the results of this analysis.

1.2 Thesis Structure

This thesis is organized into five chapters:

Chapter 1 defines the problem and provides background information on Dell Inc, the sponsor company for the project.

Chapter 2 examines in further detail the challenges faced by Dell as it begins selling through the retail channel and as it transitions some of its manufacturing capacity to ODMs. This section also contains an organizational assessment of Dell as it attempts to transform its business model.

Chapter 3 focuses on the thesis approach and states the major questions that need to be answered. In addition this chapter defines key concepts used throughout the thesis and discusses the data sources necessary to perform the analysis.

Chapter 4 describes the formulation of the linear programs used to perform the analysis contained in this thesis. This chapter highlights the purpose of the linear programs and illustrates their use through examples.

Chapter 5 discusses the results of the analysis, provides recommendations for supply chain design and proposes topics for further study.

1.3 Company Background

Founded in 1984, Dell has emerged as the world's leading direct-sale computer vendor. The company's eponymous founder, Michael Dell, started the company in his dorm-room at the University of Texas and through an innovative direct-sales and build-to-order manufacturing strategy, achieved the number 1 position in global PC market share in 2001. Headquartered in Round Rock, Texas, Dell today has annual sales of \$61 Billion USD (2008), net income of \$2.9 Billion (2008) and employs 88,200 people worldwide¹. Although it began as a PC company, Dell now offers a variety of products and services including servers, storage devices, workstations, mobility products and software and peripheral products such as printers, monitors, and projectors. These products are sold to two main customer segments: relationship buyers and transactional buyers. Relationship buyers are comprised of large corporations, government and educational institutions that generally make repeat purchases from Dell and establish a continuing relationship with Dell. Transactional buyers are consumers or small businesses who generally treat each buying decision as a separate transaction². Historically, relationship buyers have accounted for an overwhelming (over 75) percent of Dell sales.

Recently, market trends have led Dell to refocus efforts on increasing sales to transactional buyers. In addition to establishing a new Small and Medium Business Segment, Dell has created a Global Consumer Division to spur sales to consumers. Historically, consumer sales have accounted for less than 15% of Dell's total sales. Dell has made the decision to re-enter the retail space for a second time since 1990 in hopes of generating significant new business among consumers, many of whom want to physically touch and feel a unit before they buy. This new channel strategy has introduced a slew of challenges to Dell's supply chain, which have motivated the topic of this thesis. The table below illustrates the growing percentage of Dell's total sales that come from the consumer segment, up from 15% just a few years ago.

¹ (Hoovers)

² (Ngain & Gunasekaran, 2005)

Global Consumer % of Total Sales	Q3-FY08	Q4-FY08	Q1-FY09	Q2-FY09	Q3-FY09
	19.7%	24.9%	22.5%	20.4%	23.1%

Table 1: Dell Global Consumer Sales

Another major change to Dell's supply chain is a move to more CM/ODM rather than Dell-owned factories. This transition is being done primarily as a means to lower costs and be more competitive in the marketplace. This change also has significant effects on Dell's supply chain and motivates the discussion in this thesis.

1.4 Dell Supply Chain Model

Dell was founded in 1984 on a simple concept: "by selling computer systems directly to customers, we could best understand their needs and efficiently provide the most effective computing solutions to meet those needs"³. The now famous Direct Model was born and quickly developed into a source of great competitive advantage to Dell⁴. Dell allowed its customers to customize a product over the internet and successfully manufactured and delivered these computers to customers with a lead time of 5 days⁵. The Direct Model is the most efficient path to the customer, thereby forming the relationships required to truly understand customer needs⁶. There are several advantages to this business model, including access to sales information directly from the customer, ability to respond quicker to demand, retain lower levels of inventory and maintain a negative cash conversion cycle. The figure below illustrates the traditional PC supply chain with Distributors and Retailers acting as the interface between the PC Manufacturer and the Customer.

³ (Dell Corporate Website)

⁴ (Ngain & Gunasekaran, 2005)

⁵ (Spera & Ghiassi, 2003)

⁶ (Dell Corporate Website)



Figure 1: Traditional PC Supply Chain⁷

There were two main components to Dell's historical success in implementing the Direct Model: Build-to-order manufacturing (BTO) and Just-In-Time (JIT) inventory. Build-to-order manufacturing bypassed the retail channel and eliminated a potentially powerful and costly part of the value chain. Dell could schedule customized builds when customer orders were placed, which permitted Dell to employ the Just-In-Time (JIT) inventory strategy to reduce overall inventory within its supply chain and share pass on savings to the customers. The figure below illustrates Dell's Build-to-Order supply chain.

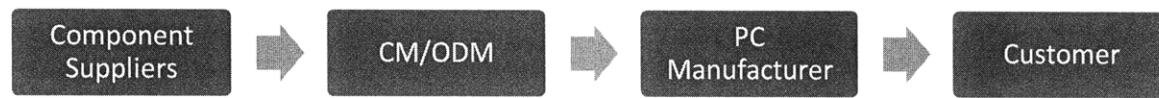


Figure 2: Dell's Build-to-Order Supply Chain⁷

In addition, Dell used a strategy of assembling the finished product close to the ultimate customer destination, to reduce lead-times and fulfillment costs. Dell has a manufacturing presence around the world to serve these customers. Dell-owned factories in the US, Brazil, Ireland, Poland, Malaysia, China and India receive orders from each region and deliver customized finished products to customers. These products include servers, storage devices, workstations, desktop computers and mobility products. Certain products are manufactured by Contract Manufacturers (CM) or Original Design Manufacturers (ODM) and are received in Dell's Distribution Centers around the world. These include non-customizable products such as printers, monitors and other peripherals.

⁷ (Kraemer & Dedrick, 2007)

2 Current Challenges

This section of the thesis examines the current situation at Dell and expands on the challenges faced by entering the Retail channel and outsourcing some of its PC manufacturing. An organizational assessment is conducted to highlight some of the key barriers this project might face. The challenges highlighted in this section form the basis of the factory capacity model discussed later.

2.1 Organizational Assessment

It is clear that both retail and ODM will require a significant shift in the mindset of Dell employees. Successfully transforming the supply chain will require a coordinated effort from several different organizations at Dell. The following is an assessment of the key organizations involved, highlighting some of the key barriers the entry into retail could face. The transition to ODM is not examined in this section, since only one particular aspect of ODM is being considered – demand disaggregation.

2.1.1 Three Lens Analysis

A Three Lens Analysis⁸ was performed in order to better understand how Dell will respond internally to the proposed changes. Developed at the MIT Sloan School of Management, a Three Lens Analysis gives the user a perspective on organizations that distills the essence of various perspectives into three distinct lenses. These are the Strategic Design Lens, the Political Lens and the Cultural Lens. The Strategic Design Lens focuses on organizational structure and the grouping, linking and aligning of the organization. The Political Lens examines the contest for power within the organization among different stakeholders with different goals and underlying interests. The Cultural Lens looks at the history of the organization and the underlying assumptions with which it functions. The three lenses together can help provide a complete picture of an organization in transition and help uncover potential barriers to change.

⁸ (Carroll, 2006)

At Dell, the Strategic lens uncovered a company in transition, the Cultural lens made apparent the polarizing effect of retail on Dell employees and the Political lens highlighted the importance of this analysis to provide a balance between the demands placed by the sales and marketing teams and the cost reduction efforts of the supply chain team. A detailed discussion of each lens follows.

2.1.1.1 The Strategic Lens

This project is being sponsored by the Americas Supply Chain Planning team within the Global Operations division at Dell. The primary responsibility of the organization is to coordinate supply (materials and finished goods) with end-user demand for North and South America. The team works with several other functions across Dell to understand customer demand and then defines raw material and factory capacity requirements for a several-month horizon. The team is responsible for coordinating the entire supply chain to ensure demand is met and oversees factory and procurement execution. The organization's strategy is to meet consumer demand, at the lowest possible cost to Dell. Making this happen requires an acute understanding of the customer and supply base. The team has consistently delivered best-in-industry transformation costs for both relationship and transactional customers. Today, with the introduction of retail sales, the focus is on understanding the needs of a new type of customer, Wal-Mart or Best Buy, with the goal of designing a low cost supply chain. This analysis will highlight a key retail customer need – large orders delivered in a short lead-time – and quantify the costs associated with meeting this need with the current supply chain. The findings from this project are critical for the Americas Supply Chain Planning team to design a better supply chain for retail.

The following diagram illustrates Dell's organization structure. It is a hierarchical organization with the Global Operations team reporting into the CEO. Within the Global Demand and Supply organization, there are separate teams for regional supply chain planning as well as a Global Retail Operations team. This team is responsible for designing a new global supply chain specifically for the retail channel and is a key stakeholder in the internship project. The Americas Operations Cell team is responsible for factory capacity planning, materials allocations

and managing customer lead-times. This team also has a dedicated sub-team for retail orders, to manually workaround traditional processes to meet specific retail needs. The internship supervisor is the manager of the Americas Operations Cell team. In addition, other key stakeholders include the Retail Sales and Marketing teams, who work directly with each retailer to identify product configurations and determine sales volumes for each retail sales cycle. The intern is highlighted in black and the key stakeholders are in white boxes.

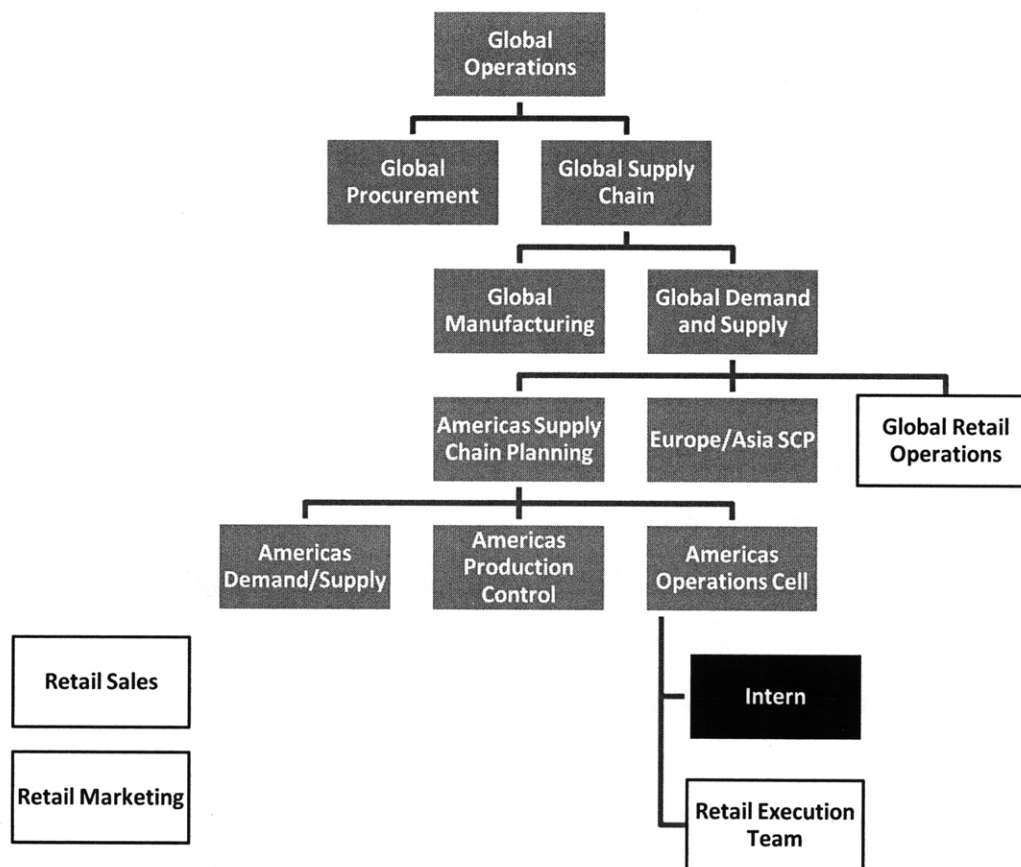


Figure 3: Dell Organization Chart

Several jobs within the retail arena have been designed to handle the unique characteristics of retail orders within Dell's existing processes. Many of these jobs involve manual tracking of parts, orders and shipments. As a result, comprehensive data is scarce and historical information is mostly gained by word of mouth. Most employees involved with retail are overwhelmed by managing the current process and do not have the time to improve the

process. A small group is considering the IT requirements for retail going forward and trying to coordinate the needs of different functions throughout Dell. This team has identified several gaps in Dell's current systems and are working to develop a long-term roadmap to address these concerns. This group is a critical source of information for the project as well as a key stakeholder. The project's findings on retail order lead-times will guide decisions on the forecast cycle and also help define raw material flow to the factories.

I believe the organization is on the right track to improving the retail supply chain and planning process. The major recommendation I have is for better information sharing between the different function (Sales, Marketing, Supply Chain) regarding long-term improvements being proposed for retail.

2.1.1.2 The Cultural Lens

The entry into retail signals a departure from a two-decade old business model for Dell. As such, it is a highly visible symbol of the new Dell. Michael Dell (the CEO), has several times reiterated the importance of success in the retail channel in transforming Dell from being a primarily commercial focused company to a broader set of customers. The difficulties encountered in the first year have brought several cultural challenges to the company. For some people, the challenges signal a need to think outside the box and not cling to Dell's traditional strengths. For others, the difficulties raise a fear of uncharted territory and reaffirm a belief that Dell's entry into retail was a big mistake.

The project is an attempt to better understand some of the challenges Dell has faced so far, by comparing the capacity needed for both the retail and direct channels and thereby quantifying a major component of channel costs. This is key to designing a new supply chain that will give Dell a chance to compete in the retail channel.

2.1.1.3 The Political Lens

A critical interaction of key stakeholders at Dell is between the Sales & Marketing teams and the Supply Chain teams. The sales teams like to differentiate Dell with the retailers by promising quick turnaround times for orders, utilizing Dell's current build-to-order infrastructure. The supply chain teams have scrambled to make this work in the short term, but are concurrently working on identifying the most efficient supply chain for retail orders. They would like to extend order lead-times and improve planning, with the ultimate goal of reducing costs in the supply chain. The internship project is an attempt to quantify the tradeoff between order lead-time and costs to provide the supply chain organization with data to back up their belief. So far, the political weight has been behind the sales teams, since the company's immediate focus is on retail growth. The sales teams have daunting volume and revenue targets and the supply chain teams have been asked to do what it takes to meet these targets. Having established a presence in retail, the focus has now turned to improving efficiencies. This has added weight behind the drive to reduce costs and given the supply chain team additional clout in increasing order lead times.

The project analysis will be complete by December, immediately after the busy Christmas selling season, where these tradeoffs will come to the fore. By demonstrating a direct relationship between supply chain costs and order lead-time, the project will guide sales behaviors and ultimately reduce supply chain costs.

2.2 Challenge of Selling Through Retail Channel

Dell's long history of Direct sales has shaped its Marketing, Finance and Supply Chain design. Today, Dell's partnership with Best Buy, Wal-Mart and Staples in the U.S. has introduced several new requirements. From the beginning of the first deal with Wal-Mart in May 2007 (Dell Fiscal Q1 2008), retail volume has grown at a tremendous annual rate, from zero to several hundred thousand units sold every quarter. Today, retail sales account for a significant portion

of Dell Consumer sales in the US. This dramatic increase in retail sales has strained Dell's build-to-order supply chain and requires a new approach.

To begin with, Dell has had to align its sales with the retail cycle in the US. Most major retailers have either three or four buying cycles in a year. All order and delivery planning takes place around the buying cycle. Details of a typical US Retail Buying Cycle with four cycles are shown in the figure below.

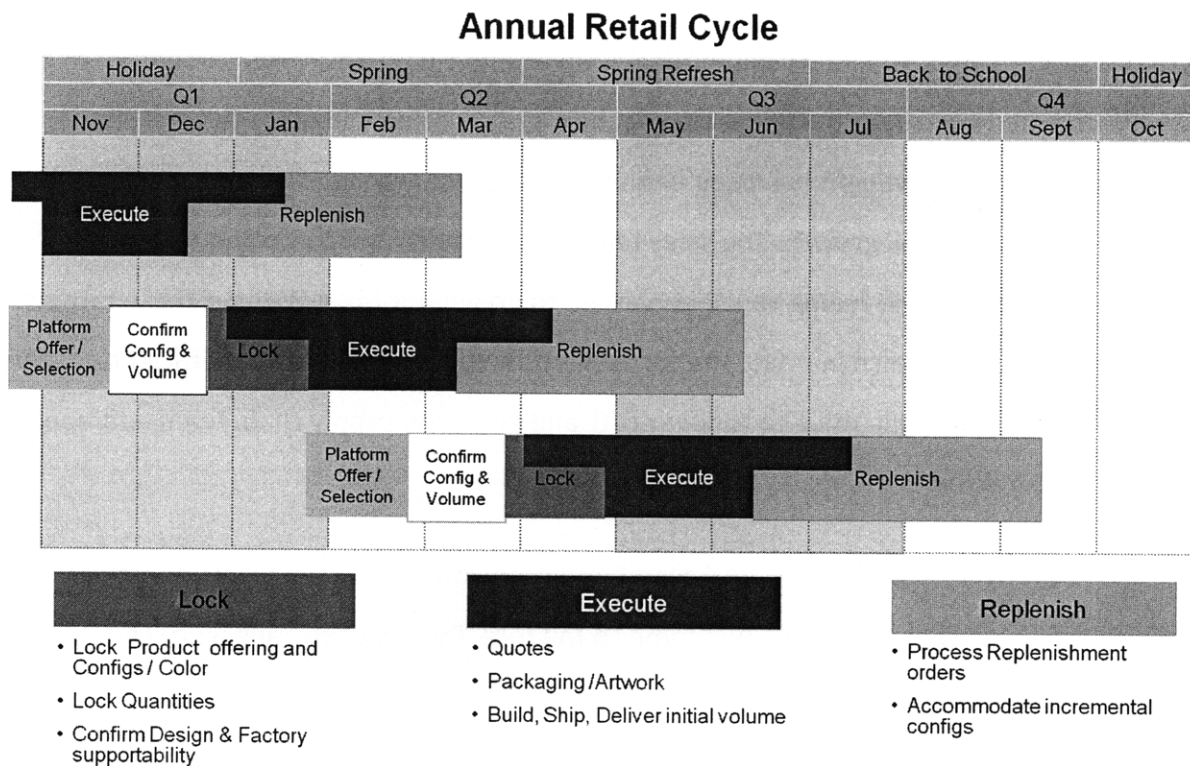


Figure 4: Typical Retail Buying Cycle

Each buying cycle is characterized by a planning phase and an execution phase. The planning phase consists of internal efforts and discussions with the retailer, to decide what products Dell will offer in stores the following cycle. This includes Platform and Offer Selection and Configuration and Volume Confirmation. The planning phase ends with the product configuration and volumes being confirmed (locked) with each retailer. At this time, Dell should have a good idea of what orders to expect from the retail channel in the next cycle. The

execution phase consists of preparations for build, delivery of the initial orders (initial fill) and replenishment throughout the cycle. In general, a large percentage of the orders for the cycle are delivered during the initial fill period. The replenishment period is composed of replenishment orders for the product configurations offered during initial fill and new “Burst” configurations. These Burst configurations are promotions of new product configurations that retailers could demand on a shortened planning cycle. These can be very important to Dell’s top line, but place pressure on the supply chain with the short cycle times involved. The figure below details Dell’s current process for handling retail orders.

Dell US Retail Process Flow

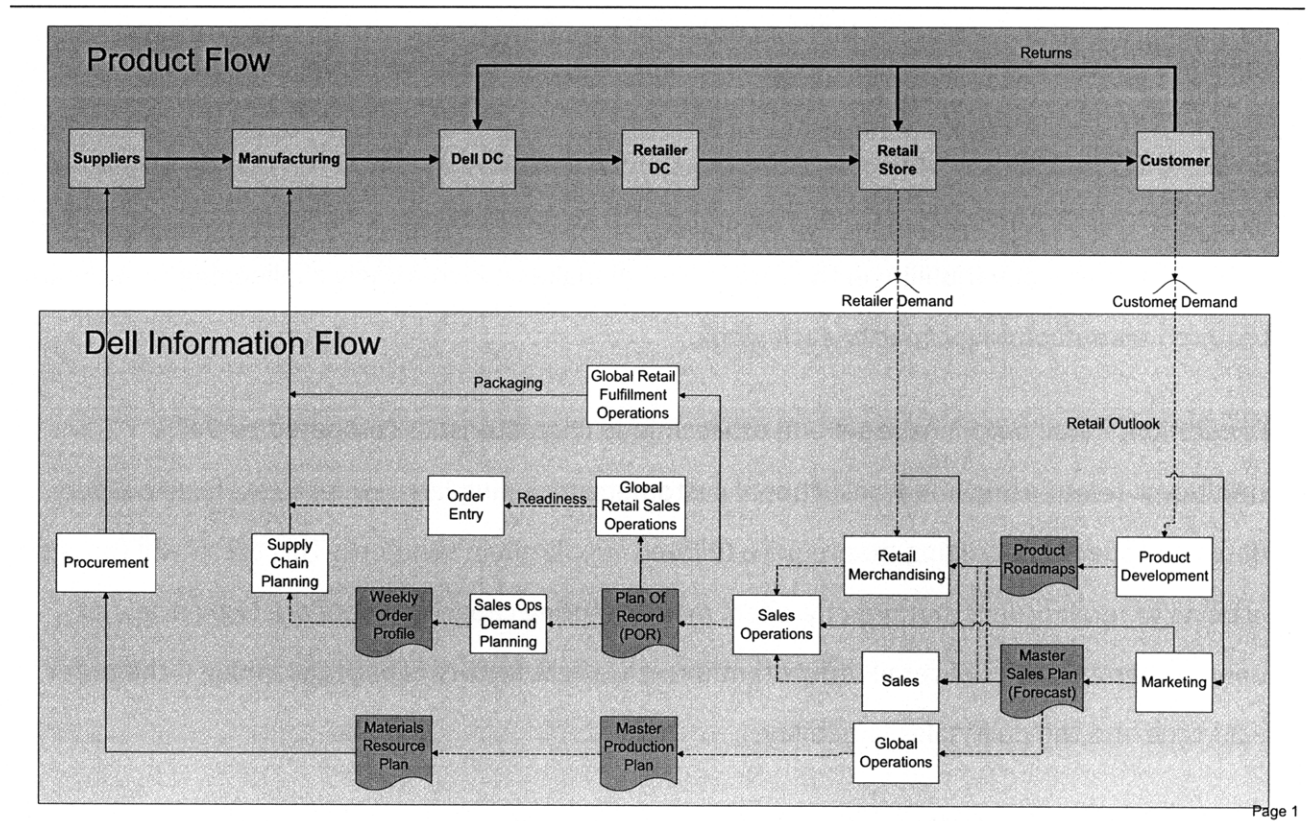


Figure 5: Dell Retail Process Map

The product flow is similar to that in the direct channel. Dell receives components from an assortment of suppliers, manufactures PC’s on a build-to-order basis in its own factories or CM/ODM’s and then generally ships the products to a Dell owned distribution center. At this

point, instead of shipping directly to the end-user, as in the direct channel, Dell will ship the finished products to a retailer distribution center instead. The retailer takes ownership of the product at this time and is responsible for transporting the products to the store. Product returns through the retail channel are also handled differently from the direct channel. Customers will often return products to the retail store, and the retailer will return the products to Dell. In the direct channel, the customer returns products directly to Dell.

The internal information flow for retail orders differs greatly from direct orders. Like direct, the retail teams set sales targets using the Master Sales Plan (MPP). Retail specific teams begin discussions with retailers several months before the purchasing cycle. These discussions feed into the production forecast or MPP. As orders are confirmed with retailers, they are placed on the Plan of Record (POR) and the MPP is updated to reflect the new order profile. Unlike the direct channel, where the average order size is under 5 units, the retail channel has extremely large order sizes. Therefore, any change in the POR generally makes a significant change to the MPP. This source of variability in the retail channel makes it increasingly challenging to estimate required manufacturing capacity each week.

In addition, Retail orders have several other unique characteristics compared to Dell's traditional relationship and transactional customers, including large order sizes, fixed delivery dates and special packaging that require tailored supply chain solutions. This thesis will focus on aspects of retail orders that directly affect manufacturing capacity. There are two particular unique characteristics of retail orders that directly affect factory capacity planning - the order lead time and the daily sales variability.

2.2.1 Order Lead Time

Retail order lead times are different from Dell's traditional transactional customers. A customer in the direct channel places an order on the Order Entry date (OE). Before the order can be built, the customer payment must get authorized which can take anywhere from zero to ten days (OE – IP) depending on the method of payment (credit card, purchase order, check, etc.).

Once authorized, the order is ready for factory build (TP). Once the order has been built, packaged and is out the factory door to be delivered to the customer, it is considered a ship complete (SC)⁹.

In general, the time between OE and TP can be considered Manufacturing Buffer time, since build and ship times are more or less fixed. The longer the Manufacturing Buffer time, the better Dell can smooth factory production. The figure below shows the typical order to delivery process for the direct channel at Dell.

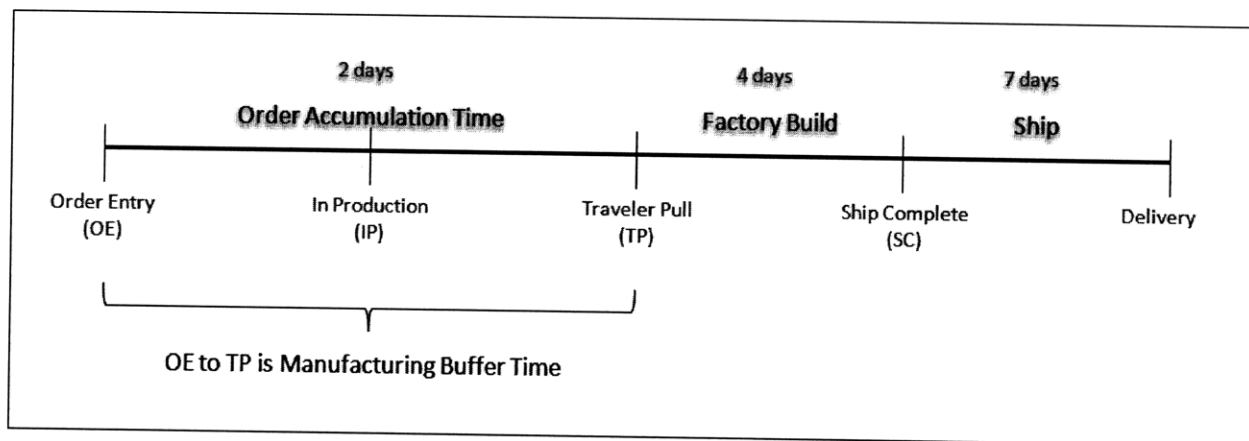


Figure 6: Direct channel order cycle time

Most customers that purchase PC's through the direct channel expect their orders to be delivered within two weeks. By contrast, retailers like Best Buy and Wal-Mart place orders for systems with target lead-times of one month. Within Dell, it was believed that the increased order lead-time in the retail channel would make it easier to schedule manufacturing capacity in advance and use retail orders to smooth out production schedules. However, in the early going, Dell has found it increasingly difficult to adhere to the one month lead-time target due to the drastically different planning cycle of retail. On several occasions, the actual lead-times have been far shorter than one month. Based on data collected for consumer notebooks sold in the US between May and July 2009, a comparison was made of order cycle times for orders made through the retail and direct channels. Order cycle time is measured from when the

⁹ (Dhalla, 2008)

customer places the order (Order Entry) to when the product is delivered to the customer (Must-Arrive-By-Date in case of retail customers). A major difference between the consumer retail and direct channels is the average order size. A consumer on Dell.com most often purchases 1 system. Retail orders can run in the several thousands. This large order size requires additional processing including accumulation and merging that take several additional days. It was believed that the Order Accumulation Time (number of days an order could be accumulated before factory build in order to meet delivery date) was far longer for retail. However, a careful analysis revealed otherwise. After taking into account the additional processing required for retail orders, it was found that the number of days available in the queue before factory build were much closer than expected. The figure below show the timeline for retail orders from order through delivery at Dell.

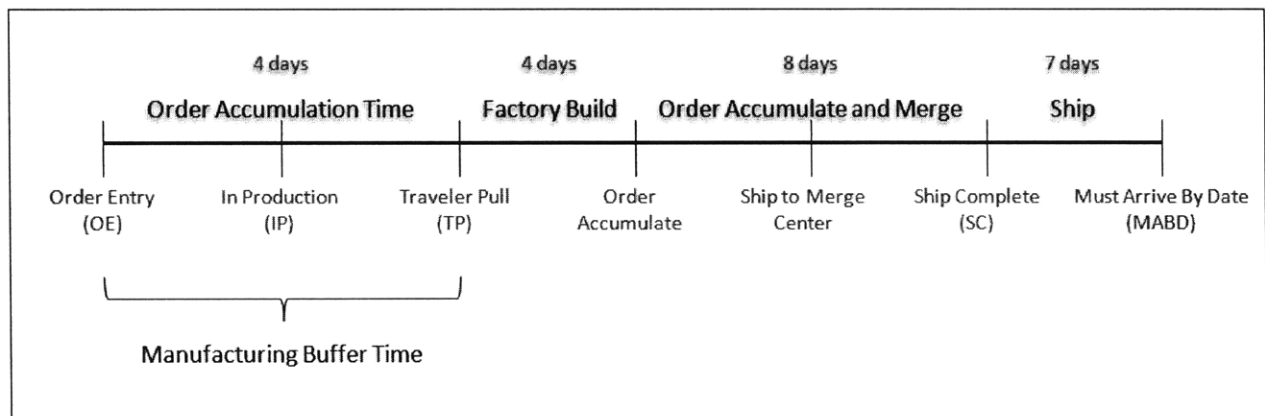


Figure 7: Retail channel order cycle time

2.2.2 Sales Variability

In operations theory, one of the three ways to improve process performance is to decrease variability in customer interarrival and processing times¹⁰. In the case of Dell, the variability of customer demand directly affects the performance of its supply chain. Retail orders have more daily and weekly volume variability than direct orders because orders are placed in large

¹⁰ (Anupindi, Chopra, Deshmukh, Van Mieghem, & Zemel)

batches. Retailers generally place orders for several thousand systems at one time, as discussed above. In addition, the order pattern in retail is dramatically different from direct. The figure below shows the typical order patterns for the retail and direct channels over a three month period.

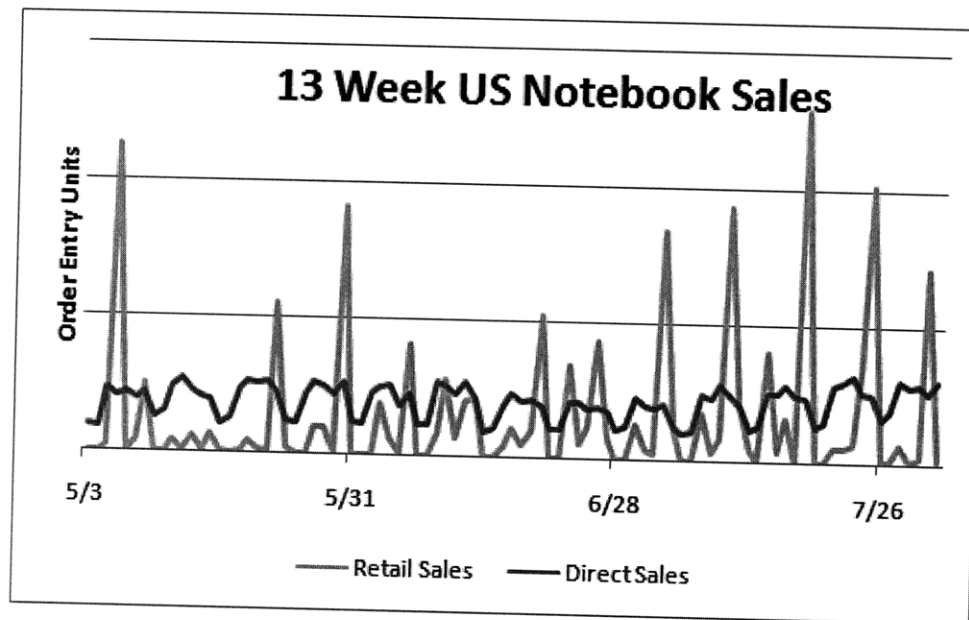


Figure 8: Sales Variability – Direct versus Retail Channel

Within a fiscal quarter, direct sales follow a steady daily demand pattern, increasing towards the end of the quarter. Day-to-day sales are comparable, with few major sales spikes or lulls. Retail sales, on the other hand, have large spikes with tens of thousands of systems sold followed by periods with low sales. With a large enough order-lead time, this is not a concern, since these large orders can be scheduled over several weeks in the factories. However, at lower lead times, the order volatility can create a production scheduling challenge, requiring overtime on certain weeks to reduce backlog, while having extended periods of scheduled production with few orders. As the table below illustrates, weekly direct sales generally vary between 80% and 125% of the average weekly sales. By comparison, weekly retail sales vary from between 20% and 200% of average weekly demand. This greater level of sales variability is a major challenge in the retail channel.

% of Average	direct	Retail
Low	80%	20%
High	125%	200%

Table 2: Weekly Lows and Highs as % of Average Weekly Demand

2.3 Challenge of Moving to Outsourced Manufacturing

Dell's proposed move to outsource more of its PC manufacturing will have major implications for supply chain design. There are several different strategies being considered for implementation of an Original Design Manufacturing (ODM) model. Dell's supply chain will need to be significantly remodeled as ODM factories begin replacing Dell factories worldwide. All the far reaching effects of outsourced manufacturing on Dell's supply chain are out of the scope of this thesis. The thesis will focus on one particular aspect of the transition to ODM that can significantly affect Dell's factory capacity planning in the future – the effect of demand disaggregation into multiple factories.

Dell currently has one large notebook factory in Asia that produces a majority of all notebook products for the global market. This factory benefits from economies of scale and scope, with several different notebook models accounting for millions of notebooks shipped annually. This pooling of demand leads to significant supply chain benefits. With a transition to ODM, it is likely that notebook demand will be disaggregated into several smaller factories. This thesis will attempt to quantify the potential risks and benefits of this implementation approach. Our analysis will be based on the principle of aggregation, which states that the standard deviation of the sum of random variables is less than the sum of the individual standard deviations. As long as available capacity is shared among various sources of demand – pooling capacity – we can achieve the benefits of aggregation¹¹.

¹¹ (Anupindi, Chopra, Deshmukh, Van Mieghem, & Zemel)

Two specific factors will need to be considered when disaggregating demand for notebooks across multiple factories. These are discussed in more detail below.

2.3.1 Demand Patterns for Notebook Platforms

Today, Dell's notebook factory is somewhat immune from demand at a platform (model) level. Capacity planning is done at an aggregate volume level and the mix of models built are less relevant for factory capacity decisions. Dell is well placed to handle surges or lulls in demand for a particular product, as long as aggregate demand is below capacity. In addition, Dell can manage the different annual demand patterns for each model under the roof of one factory. For example, a surge in demand for consumer notebooks during Christmas can be accommodated due to a slowdown in corporate notebook sales during the holidays. By splitting up notebook capacity by platform into multiple factories, Dell could potentially lose some of this pooling benefit. Data collected for Americas notebook sales between May and July 2008 supports this theory. The graph below depicts the sales of the top four notebook platforms. Platform A had a peak in week 14, which coincided with a lull in demand for the other platforms. Platform A had a lull in week 21 and 22, where sales of other platforms increased. In both these cases, if these platforms were each built in separate factories, some factories would have required significant overtime to handle the surge in demand, while others would stand idle. Manufacturing all platforms under one roof could avert this situation in many cases.

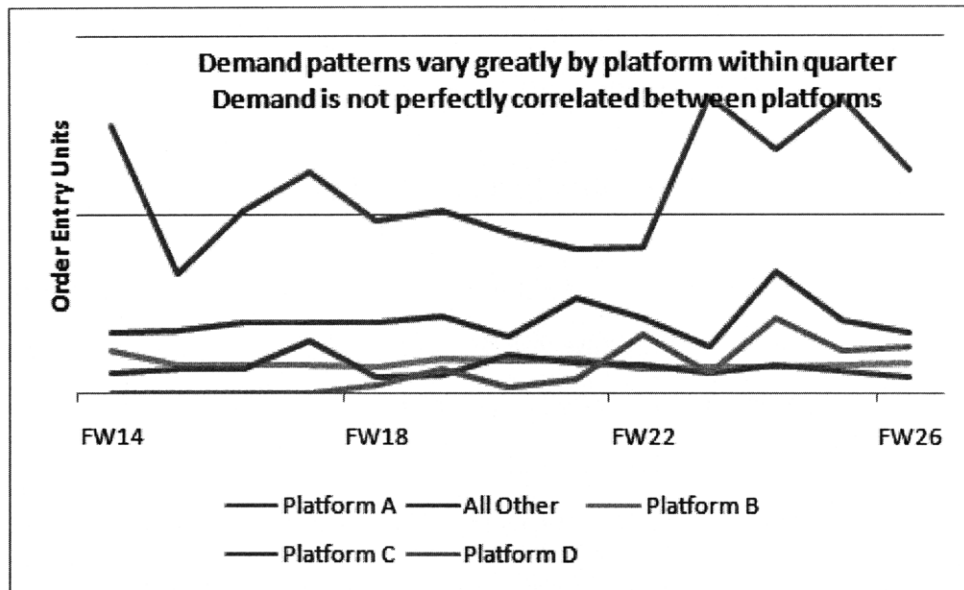


Figure 9: Demand for various Notebook Platforms

2.3.2 Forecast Accuracy

Operations theory states that demand forecasts are more accurate at an aggregate level than at an individual component level¹². Intuitively, aggregation reduces the amount of variability relative to aggregate mean demand. This is because high and low demand patterns among individual products tend to cancel one another, thereby yielding a more stable pattern of total demand. Data collected for Americas notebook sales between May and July 2008 supports this theory. Forecast accuracy was measured by comparing actual sales data for each notebook model with Dell's demand forecast made at two different periods.

$$\text{Forecast Accuracy} = (\text{Actual Demand} - \text{Forecast Demand}) / \text{Forecast Demand}$$

The graph below depicts the forecast accuracy of the top four notebook platforms during this period.

¹² (Anupindi, Chopra, Deshmukh, Van Mieghem, & Zemel)

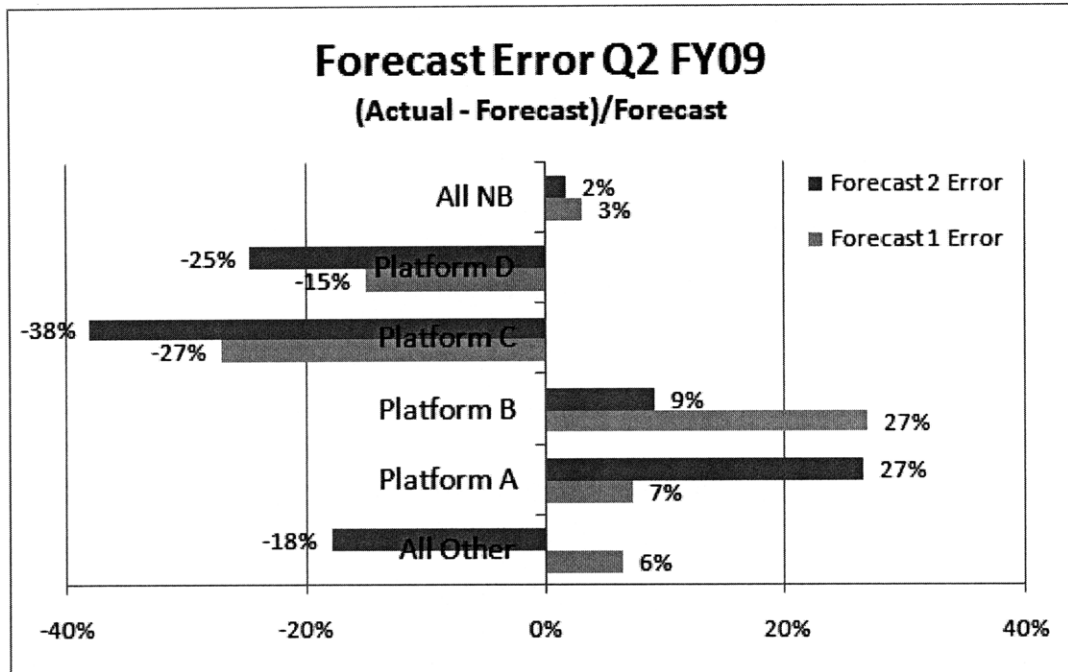


Figure 10: Notebook Forecast Accuracy

This data clearly illustrates the vast improvement in demand forecast accuracy at an aggregate level over platform level. Platforms A and B have a negative bias, i.e. the forecasted demand was lower than actual sales. Platforms C and D have a positive bias, i.e. the forecasted demand was higher than actual sales. As a result of these biases cancelling each other out, the aggregate forecast error for all notebook platforms is in the low single digits, compared to over 20% in case of some of the platforms. This fact could have implications on an ODM implementation that disaggregates demand into multiple factories by platform.

3 Project Methodology and Approach

Both the issues being examined in this thesis – retail sales and ODM production – directly affect the performance of Dell’s supply chain. According to Anupindi et al (2006), the key levers to improve process performance are the following:

1. Decrease variability in customer interarrival and processing times
2. Increase safety capacity
3. Synchronize the available capacity with demand

Therefore, if demand variability increases, it must be compensated by adding safety capacity or by better synchronizing demand to available capacity in order to prevent process degradation. The analysis in this thesis will focus on manufacturing safety capacity, since changing processing times or attempting demand synchronization are not feasible in the short term. The thesis will attempt to quantify the relationship between sales variability, factory capacity and order lead time and determine how to improve Dell’s supply chain performance for retail orders.

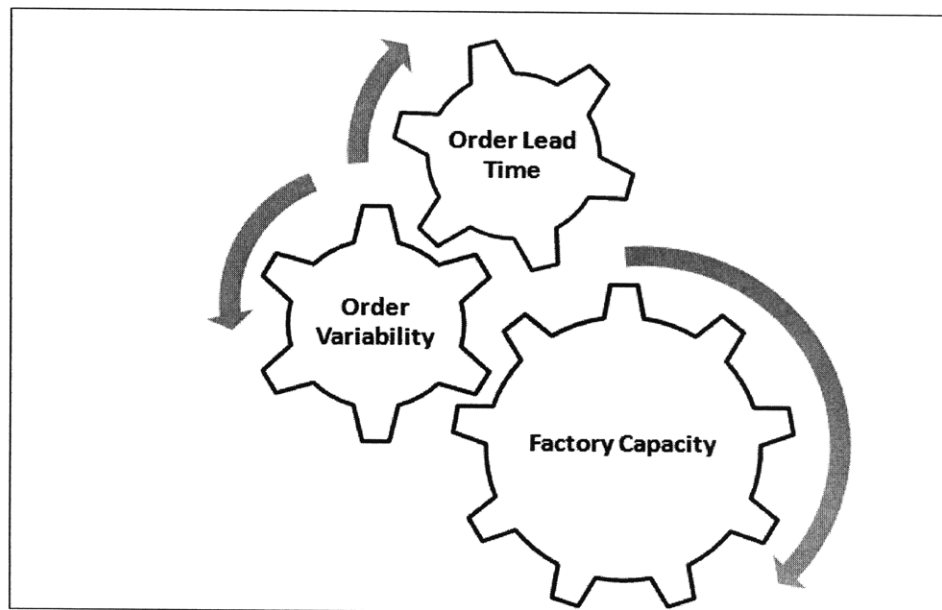


Figure 11: Supply Chain Trade-offs

Specifically, the thesis will attempt to answer the following questions:

- What impact does the added sales variability in the retail channel have on manufacturing capacity?
- What is the relationship between order lead time and factory capacity?
- Is there an optimal tradeoff between capacity investment and order lead time for the retail channel?
- What impact does demand disaggregation with ODM have on future factory capacity needs?

A linear program will be developed to quantify these relationships using Dell's historical sales data and will form the basis of our analysis.

3.1 Definition of Key Concepts

Two critical concepts are repeatedly discussed in this thesis – Factory Capacity Investment and Order Accumulation time. Both these concepts are defined and discussed in this section.

3.1.1 Definition of Factory Capacity Investment

A core goal of this thesis is to determine the factory capacity requirements for the retail channel and with ODM. The definition of factory capacity in this thesis is one of “factory investment” rather than “factory staffing”. Factory investment is defined as the maximum volume of output per period of time that a business or facility can produce¹³. Since this is the maximum capacity of the factory, it will not change from day to day during the course of the period being examined and does not vary based on shift schedules and staffing plans. Factory Capacity Investment is generally the effective or planned capacity rather than the maximum theoretical capacity of the factory, i.e. it is the expected output of the process. The figure below illustrates the difference between Factory Investment and Factory Staffing.

¹³ (Beckman & Rosenfield)

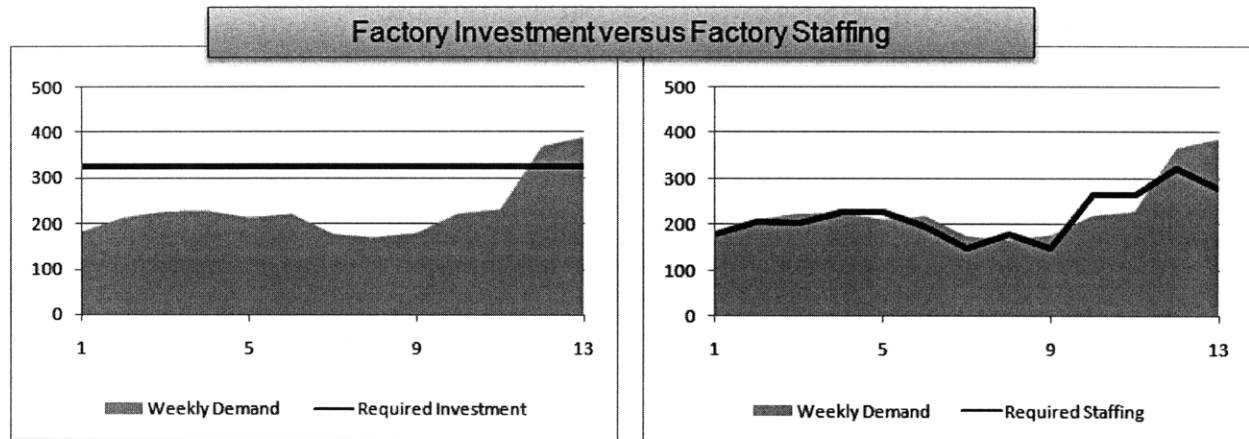


Figure 12: Factory Investment vs. Factory Staffing

3.1.2 Definition of Order Accumulation Time

This thesis will focus on quantifying a relationship between Factory Capacity, Order Lead time and Order Variability as discussed above. Chapter 2.2.1 illustrated the difference between order cycle time in the direct and retail channels. For the purpose of this analysis, we will dissect order cycle time into its component parts to isolate fixed and variable processes and determine how order lead time can be changed. As shown in Figure 7 and Figure 8, order cycle time can be dissected into pre-build and post-build components. These are shown in the figure below.

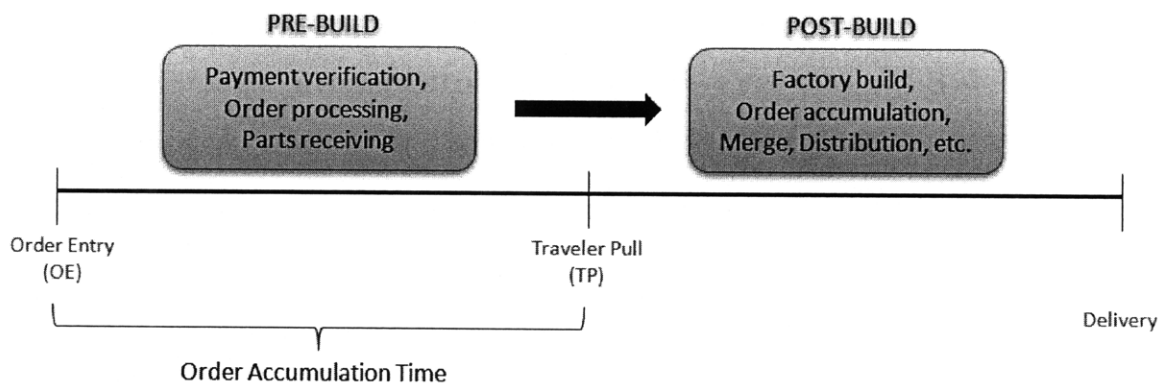


Figure 13: Definition of Order Accumulation Time

In Dell's current supply chain, the post-build processes have more or less fixed cycle times. Some of these steps, including order accumulation and delivery can be reduced over the long

term, but will be considered fixed for the purpose of this analysis. The pre-build processes are more variable and can be used as a buffer to allow for level production scheduling. We define these pre-build processes from Order Entry (OE) to Traveler Pull (TP) as Order Accumulation time. This is in effect the number of days of manufacturing buffer between the time an order is placed and the time it must begin factory build. Order Accumulation time will be the key decision variable used in the linear program and will form the basis of our analysis on factory capacity tradeoffs.

3.2 Data Collection

Several data sets were used to perform the analysis required in this thesis. Dell sells products to relationship and transactional customers across the globe. The scope of this analysis was restricted to the US market, since retail penetration is highest here and the data was readily available. It must be noted that the findings from this thesis could vary depending on global region. In addition, Dell sells a variety of products through both the retail and direct channels, including notebooks, desktops, monitors, printers, projectors and ink. For the purpose of this analysis, it was decided to focus on notebook sales only. Notebooks accounted for a majority of sales in the retail channel in the US and occupy a special importance in Dell's retail strategy. Moreover, notebook production is more easily outsourced and hence the transition to ODM will be piloted with notebooks first. The model was also run for desktop platforms and the findings were similar to those for notebooks.

Due to the short history of retail sales at Dell, historical data was limited. The first quarter with complete data for Dell retail sales was Q2 Fiscal Year 2009 (May – July 2008) . The data from this period was used to perform the analysis. It should be noted that sales patterns vary by quarter and the findings quantified by this thesis may vary by timeframe. Most of the required data was obtained through Dell's IT systems, although some retail specific data had to be collected manually. The following data was used to perform the analysis:

- Sales Data: Order Entry data was obtained for all US notebooks sold between May and July of 2008. Order Entry occurs when a purchase has been approved and is a close proxy to actual sales. This data was obtained for each day in the quarter, separated by platform (model). The figure below shows a sample of the weekly sales profile for the direct and retail channels.

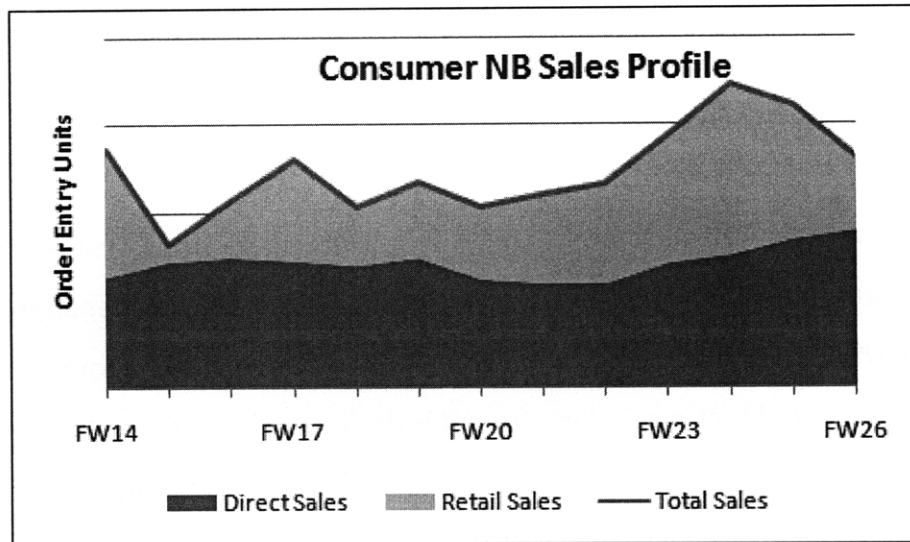


Figure 14: Direct and Retail Sales Quarterly Profile

Similarly, the figure below shows a sample of the daily notebook sales data for the direct and retail channels. Channel specific data will be needed for comparison at an aggregate level of capacity requirements between the direct and retail channels.

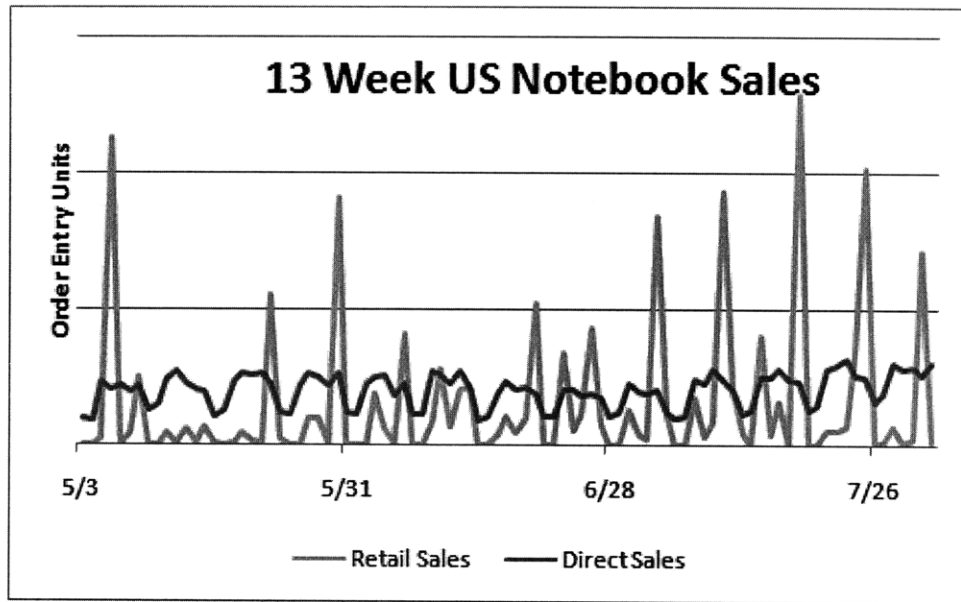


Figure 15: Sales Variability – Direct versus Retail Channel

Further, this data was also compiled for each individual desktop and notebook platform sold in the US. The figure below shows the daily sales data for some of the higher volume platforms. Platform level data will be used for two purposes – to verify that the results obtained for aggregate channel sales apply to individual platforms and to calculate the impact of potential disaggregation of demand into multiple factories through ODM.

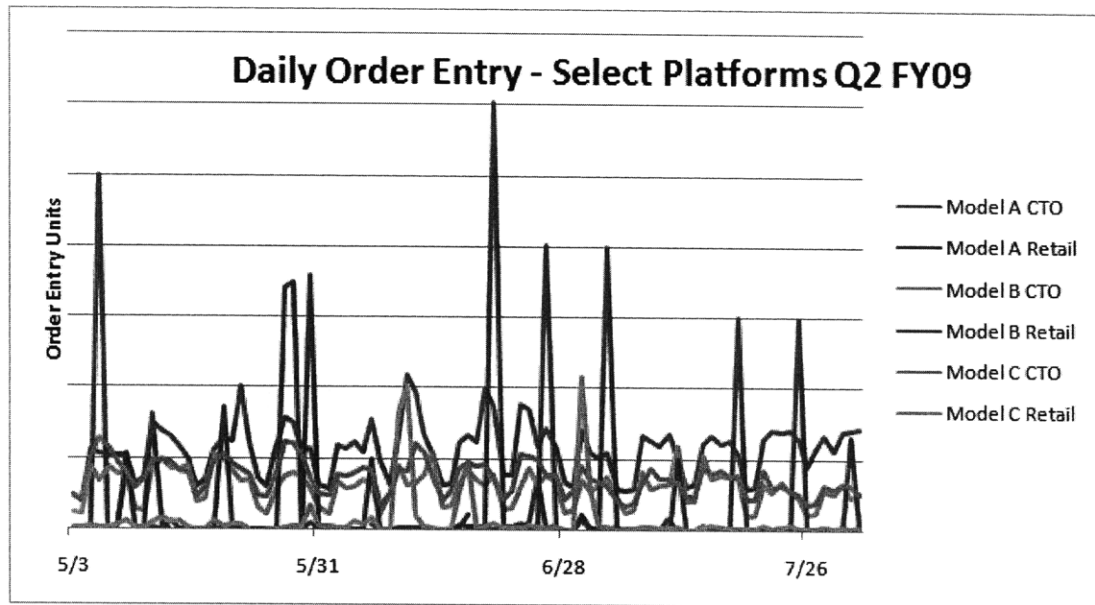


Figure 16: Sales Data by Notebook Model and Channel

- **Forecast Data:** Dell creates a Master Sales Plan (MSP) as a high-level forecast for each quarter. The MSP forecasts sales by month for each platform. The MSP is used to create a Master Production Plan (MPP) which adds additional granularity and adjusts for product transitions, part shortages and other operational factors. The MPP forecasts sales by week for each platform. For this analysis, the MPP data was used as a forecast for each platform during the quarter.
- **Cycle Time:** Cycle time data was obtained from multiple sources to measure the time between sale and delivery for both the retail and direct channels. This was used to compute the average and median cycle times and order accumulation times used in the analysis.

4 Model Functionality and Development

Two linear programs will be developed to establish a relationship between factory capacity and order lead-time. The data sets described above will be used as various inputs to the model. The first model (Capacity Investment Model) will calculate the minimum factory capacity investment required for a set of orders depending on the lead-time. The second model (Order Accumulation Time Model) will calculate the minimum order accumulation time required for a set of orders if a restriction is placed on factory capacity. The following sections detail the two linear programs, the decision variables, assumptions and calculations.

4.1 Capacity Investment Model

The Capacity Investment Model will be used to calculate the minimum factory capacity required to fulfill a given set of orders within a given lead-time. The purpose is to establish a relationship between factory capacity and lead-times for a variety of different order profiles. This program will be used to compare the capacity requirements of retail versus the direct channel and also to estimate the effect of demand disaggregation with ODM. The program will be run using various data sets, including daily retail sales, daily direct sales and daily sales for each individual notebook platform. The following sections describe this model in further detail.

4.1.1 Linear Program Formulation

Objective Function:

$$\min C$$

Subject to:

$$T_{wd} - C \leq 0 \quad \text{for all } w, d$$

$$T_{wd} - A_{wd} \leq 0 \quad \text{for all } w, d$$

$$C - A_{wd} / OA \geq 0 \quad \text{for all } w, d$$

$$C \geq 0$$

$$A_{wd} = A_{(wd-1)} - T_{(wd-1)} + S_{wd}$$

Where,

Indices:

w : week of the time period

d : daily sequence number of the week (Mon = 3)

Decision Variables

C : daily factory capacity in units

T_{wd} : factory throughput on day d of week w in units

A_{wd} : # of units available to build on day d of week w

Input Data

S_{wd} : # of units sold on day d of week w

OA : days of allowed order accumulation time

4.1.2 Model Features

The Capacity Investment Model is used to determine the minimum factory capacity required for a particular set of orders during the time period for a certain Order Accumulation Time. The linear program minimizes the total factory capacity for a certain time period by optimizing the daily factory capacity (C) and daily throughput (T_{wd}). The model uses daily sales (S_{wd}) data and Order Accumulation time (OA) as inputs and then computes the number of products manufactured each day (T_{wd}). In order to compute throughput, the model also calculates the number of products available to build (ATB) each day (A_{wd}). The daily throughput is then constrained by the available factory capacity and ATB, i.e. the factory cannot manufacture more than its capacity or the number of products available to build. Intermediate Variables V1 and V2 are used to constrain the number of days of ATB to be less than the OA Time in a linear manner.

This ensures that the factory will always maintain a backlog less than that allowed by the Order Accumulation time (allowed queue length).

4.1.3 Assumptions

The Capacity Investment Model makes some implicit assumptions that are discussed below.

- 100% forecast accuracy. For the purpose of comparison, historical sales data was used to compute the factory investment that would have been necessary to manufacture all those products within a certain time frame with a certain lead-time. This use of historical data assumes 100% accuracy of the sales forecast, which is not true. This assumption understates the total capacity requirement for a given set of orders, but does not bias the result in the case of a comparison.
- 7-day work week. The factory investment assumption made above implies a 7-day work schedule, since it is the maximum available capacity daily.
- Instant Factory Build-Time: The model assumes that any product could be manufactured in the factory within a day. Therefore, if the factory capacity was large enough, any number of available products up to that capacity could be manufactured within the day. This assumption does not affect the analysis, since the comparison is being made for Order Accumulation (OA) times and not overall cycle times. OA time simply measures the number of days of buffer available before a product must be built in order to meet the delivery date. So anything after the start of build is irrelevant to the model and has already been considered in the initial analysis of cycle times.
- Inventory Holding. The model assumes that there is no special restriction on parts inventory depending on the time of the quarter or year. Therefore, the only restriction to the number of days of parts inventory is the number of days of OA. This ignores certain internal inventory management rules at Dell, including lowering inventory levels

at the end of a fiscal quarter. This assumption will not bias the result of any comparison performed using the model.

4.1.4 Excel Solver Implementation

The Capacity Investment Model was implemented using Microsoft Excel Solver. The figure below shows a snapshot of the Solver model. The objective function is highlighted in blue, the decision variables are highlighted in green and the inputs are highlighted in yellow.

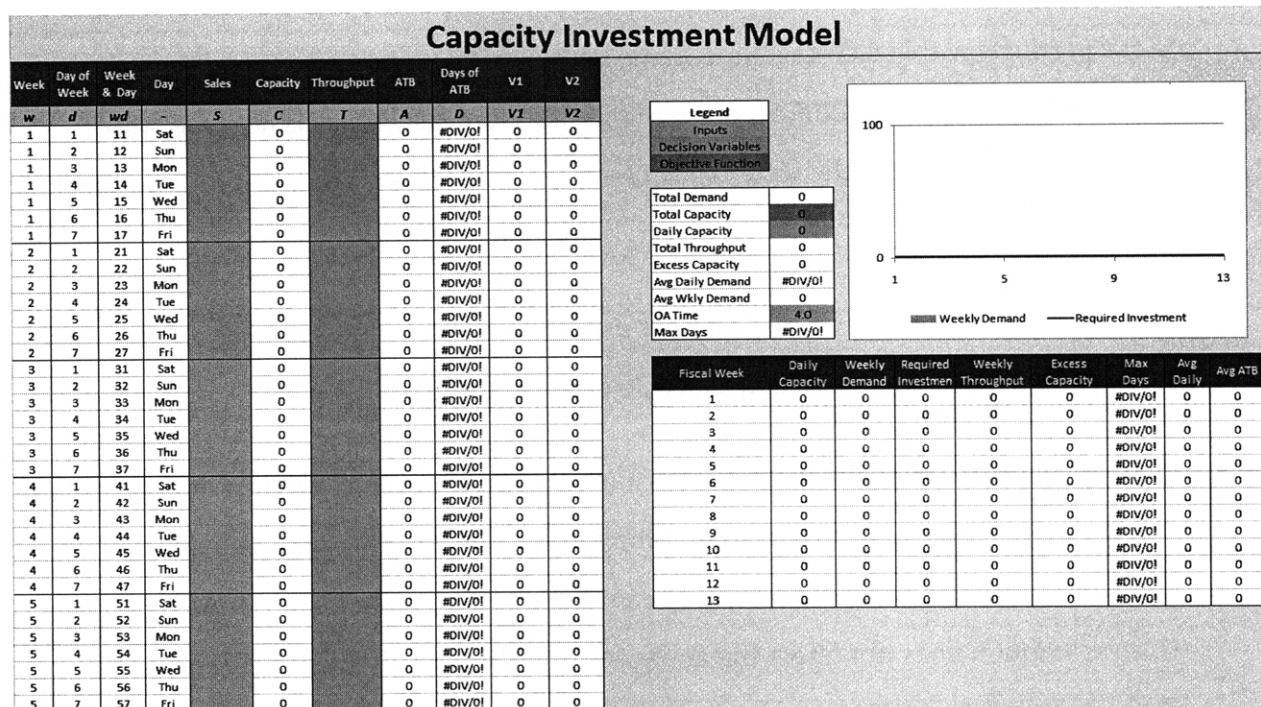


Figure 17: Capacity Investment Model Excel Solver Implementation

Sales data for a given time period is input into the excel model. The user will also need to input the Order Accumulation (OA) time. Solver will then compute the factory throughput for each day based on an optimized daily factory capacity. This factory capacity is the minimum capacity investment needed to fulfill the given set of orders within the Order Accumulation time. The user can vary the OA time to determine the optimal factory capacity at different lead times.

4.1.5 Model Example

As an illustration, the Excel model will be run for a set of orders to determine the required factory capacity. The sales data illustrated in the figure below mimics a typical order pattern for notebook sales through the direct channel at Dell for a quarter. The sales are fairly steady each week throughout the quarter, increasing towards the end of the quarter. The graph also displays the average daily sales during the quarter.

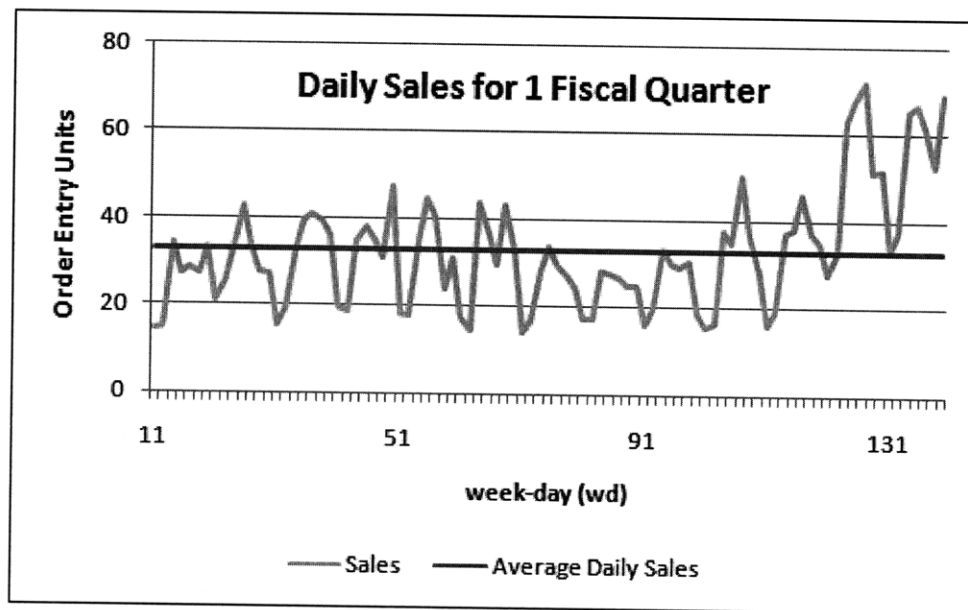


Figure 18: Sample Sales Data for Example

An Order Accumulation time of 4 days is used in this example. Using these inputs, the model will compute the daily throughput and minimize total capacity. In this example, it was determined that the required factory investment for the order profile was 46,336 units. Therefore, Dell will need to build a factory with the capability to manufacture 46,336 units per day in order to meet the average demand of 33,056 units per day during the quarter. The difference between the required capacity and the average demand is the result of uneven demand through the quarter and the day-to-day order variability. The figure below shows the excel model with inputs and outputs as used in the example.

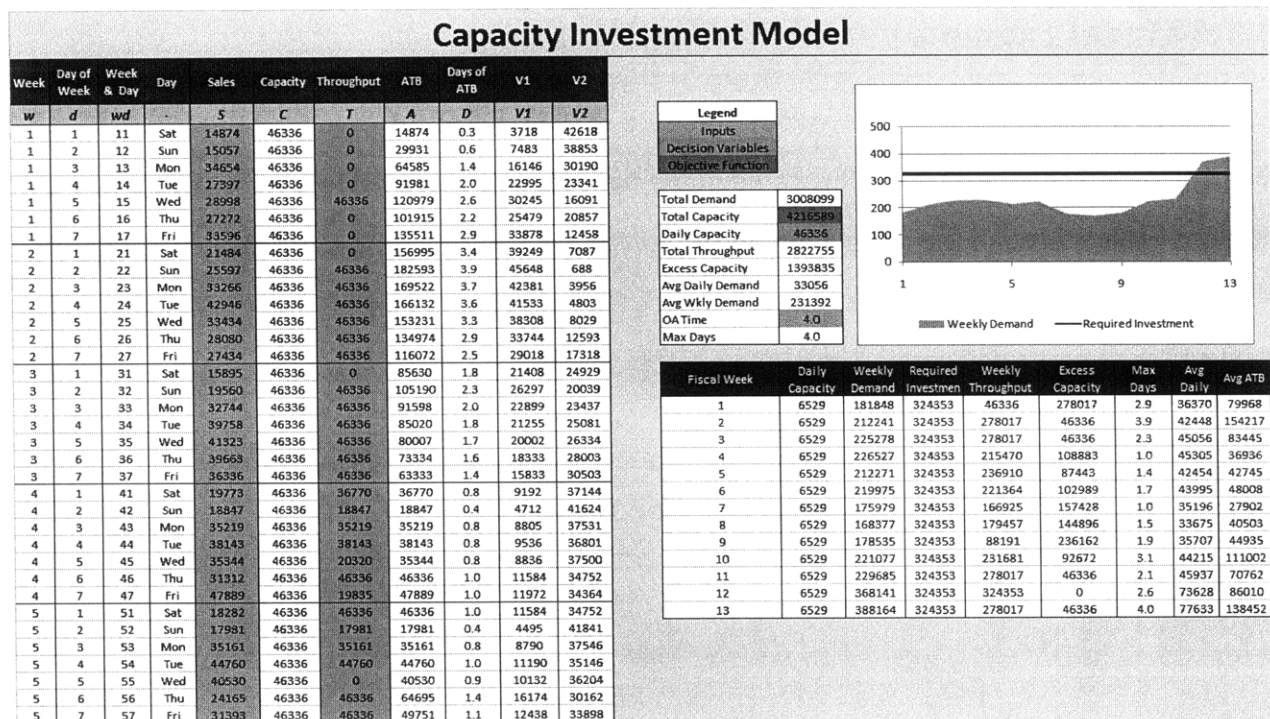


Figure 19: Capacity Investment Model Example

4.1.6 Model Scenarios

The Capacity Investment Model is used to compare the factory capacity investment in the retail and direct channels and is also used to quantify the impact of demand disaggregation with ODM. These two scenarios are discussed below.

4.1.6.1 Retail versus direct Capacity

Dell would like to know if and how factory capacity requirements will change as they sell products through both the retail and direct channels instead of only direct. For this purpose, the model was used to perform a comparative assessment of required capacity using historical sales data for both the channels. We chose to examine data for notebooks sold in the US between May and July 2008, since that was the most recent completed quarter at the time of assessment. The US market has the highest volumes and the largest variety of notebooks sold and hence was most relevant for this analysis. The figure below provides a representative sample of sales in the retail and direct channels over a fiscal quarter.

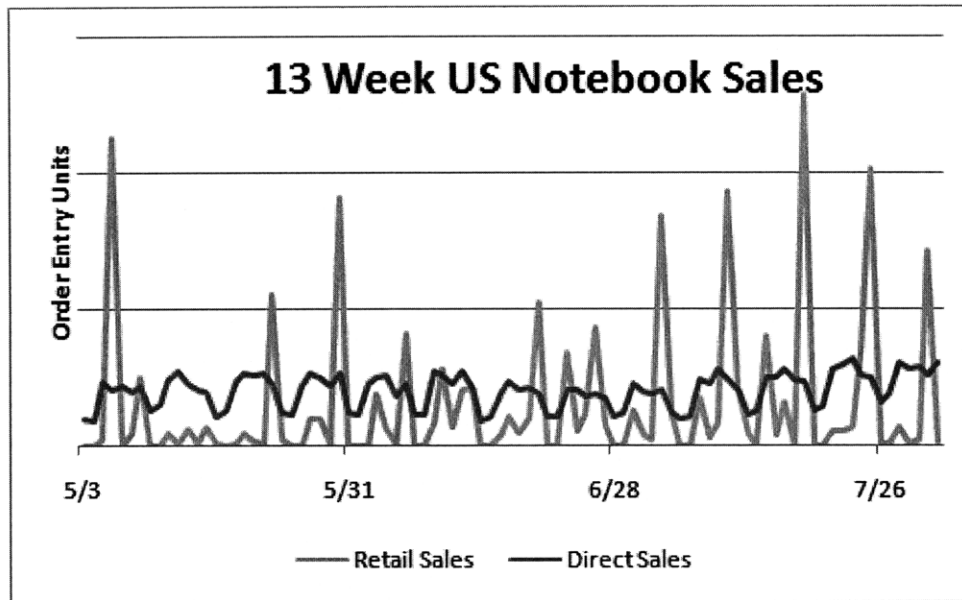


Figure 20: Direct versus Retail Channel Order Variability

Both the direct and retail sales data will be used as an input to the Capacity Investment Model. For each channel, the Order Accumulation time will be varied and the minimal capacity investment will be determined. This will involve running several iterations of the model. The resulting data will be used to perform a comparative analysis of the two channels.

4.1.6.2 Platform Disaggregation with ODM

Dell would like to understand the impact of moving from Dell owned factories to Original Design Manufacturers (ODM). Specifically, the goal of this project is to quantify the factory capacity implications of disaggregating demand from one factory to several. The model will be used to predict the additional factory investment required if demand was disaggregated into multiple factories by platform. This will be done using historical sales data for different notebook platforms. We chose to examine data for notebooks sold in the US between May and July 2008, since that was the most recent completed quarter at the time of assessment. The US market has the highest volumes and the largest variety of notebooks sold and hence was most relevant for this analysis. The model will be run to compare the two cases as shown in the figure below.

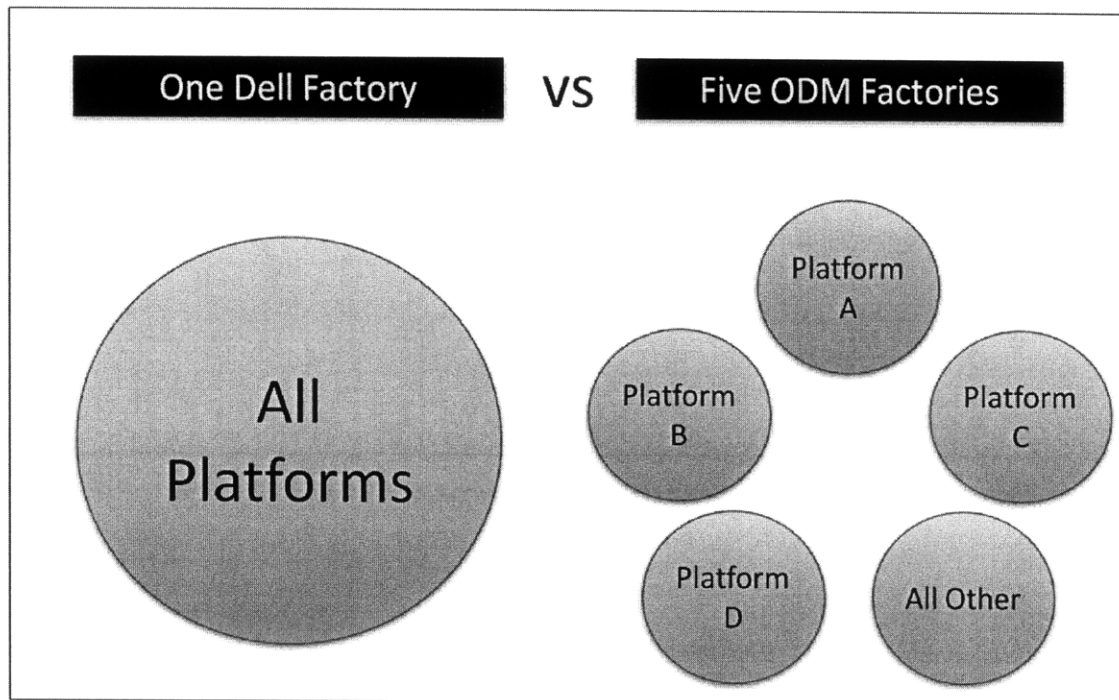


Figure 21: Platform Disaggregation with ODM

Case 1: One factory manufacturing all notebook platforms. The model will take as input aggregate demand for all notebook platforms sold in the US, through all channels during the time period. The time period used in this example is thirteen weeks. The Order Accumulation time will be varied to see how capacity needs change with differing cycle times. The table below shows a sample of the sales data used in this model for all notebooks in a two week period.

wk & day	Dell Factory
Wd	All NB
121	5457
122	6110
123	13556
124	14106
125	15607
126	23889
127	50695
131	6841
132	7824
133	14841
134	11821
135	12645
136	38950

137	12789
-----	-------

Table 3: Sample Notebook Sales Data

Case 2: Five factories. The model will be run to analyze capacity needs if demand was split into five factories, each of which would manufacture specific notebook platforms. Five was chosen for the purpose of this analysis as an example. In reality, the model can be run for any number of factories chosen depending on the scenario being considered. In this example, four of the factories exclusively manufactured one of the highest volume platforms respectively. The fifth factory manufactured all other platforms. The disaggregation of demand could be evaluated in various other combinations as desired. The model will be run for each of the five factories using sales data for the platforms assigned to that factory. The time period for this example is thirteen weeks. The model will be run for a variety of different Order Accumulation times to see how capacity needs change with differing cycle times. The figure below shows a sample of the sales data used for each of the five factories.

wk & day	ODM Factory 1	ODM Factory 2	ODM Factory 3	ODM Factory 4	ODM Factory 5
Wd	Platform A	Platform B	Platform C	Platform D	All Other
121	2702	583	219	881	1072
122	3158	612	234	898	1208
123	6101	1289	696	1607	3863
124	6471	1404	571	1583	4077
125	8351	1380	714	1777	3385
126	18194	1398	576	1446	2275
127	37633	1325	3470	3632	4635
131	3222	899	249	1170	1301
132	3648	1139	268	1235	1534
133	6261	1328	578	2153	4521
134	6339	1121	524	1519	2318
135	5925	1387	680	2399	2254
136	30029	1410	1771	2698	3042

Table 4: Sample Notebook Platform Sales Data

4.2 Order Accumulation Time Model

The model discussed in this section is similar in structure to the Capacity Investment Model. However, in this case, the allowed capacity is provided as an input and the model calculates the minimum Order Accumulation time required to fulfill a given set of orders within the available

capacity. With this model, managers can input the available factory capacity into the model and determine what theoretical minimum lead-time can be offered for a product. While offering the same results as the Capacity Investment Model, the Order Accumulation Time Model could be of more practical use for managers, since in most scenarios factory capacity cannot be changed in a short period of time, whereas the order cycle-time can be modified if necessary. Thus, a manager can input the current available factory capacity into the model, determine the order accumulation time and evaluate what lead-time will be needed to be published to customers.

4.2.1 Linear Program Formulation

Objective Function:

$$\min OA$$

Subject to:

$$C \geq 0$$

$$T_{wd} - C \leq 0 \quad \text{for all } w, d$$

$$T_{wd} - A_{wd} \leq 0 \quad \text{for all } w, d$$

$$D_{wd} - OA \leq 0$$

$$A_{wd} = A_{(wd-1)} - T_{(wd-1)} + S_{wd}$$

$$C = k * \frac{\sum_{w=0}^W \sum_{d=1}^7 S_{wd}}{W * 7}$$

$$D_{wd} = \frac{A_{wd}}{C}$$

Where,

Indices:

w : week of the time period

d : daily sequence number of the week (Mon = 3)

Decision Variables

OA : Order Accumulation time in days

T_{wd} : factory throughput on day d of Week w in units

Input Data

S_{wd} : # of units sold on day d of week w

k : allowed daily factory capacity as % of average daily sales

Intermediate Variables

A_{wd} : # of units available to build on day d of week w

D_{wd} : # of days of ATB

4.2.2 Model Features

The Order Accumulation Time Model is used to determine the minimum Order Accumulation time required for a particular set of orders during the time period with a certain allowed factory capacity. The linear program optimizes Order Accumulation time for a set of orders for a limited factory size. The model uses the daily sales (S_{wd}) data as an input and then computes the number of products manufactured each day (daily throughput T_{wd}). In order to compute throughput, the model also calculates the number of products available to build each day (A_{wd}). Daily throughput is then constrained by the available factory capacity and ATB, i.e. the factory cannot manufacture more than its capacity or the number of products available to build. Also, in this case, since we are setting the available factory capacity as an input, daily factory capacity is calculated as a percentage (k) of daily average sales. Another calculation performed is one for Days of ATB (D_{wd}), which is calculated by dividing ATB by Daily Capacity. The Days of ATB are then constrained by the Order Accumulation time (allowed queue length). This ensures that the factory will never hold more ATB than that allowed by the Order Accumulation time.

4.2.3 Assumptions

The assumptions made for this model are identical to the ones made above for the Model to Calculate Capacity Investment.

4.2.4 Excel Solver Implementation

The Order Accumulation Time Model was implemented using Microsoft Excel Solver. The figure below shows a snapshot of the Solver model. The objective function is highlighted in blue, the decision variables are highlighted in green and the inputs are highlighted in yellow.

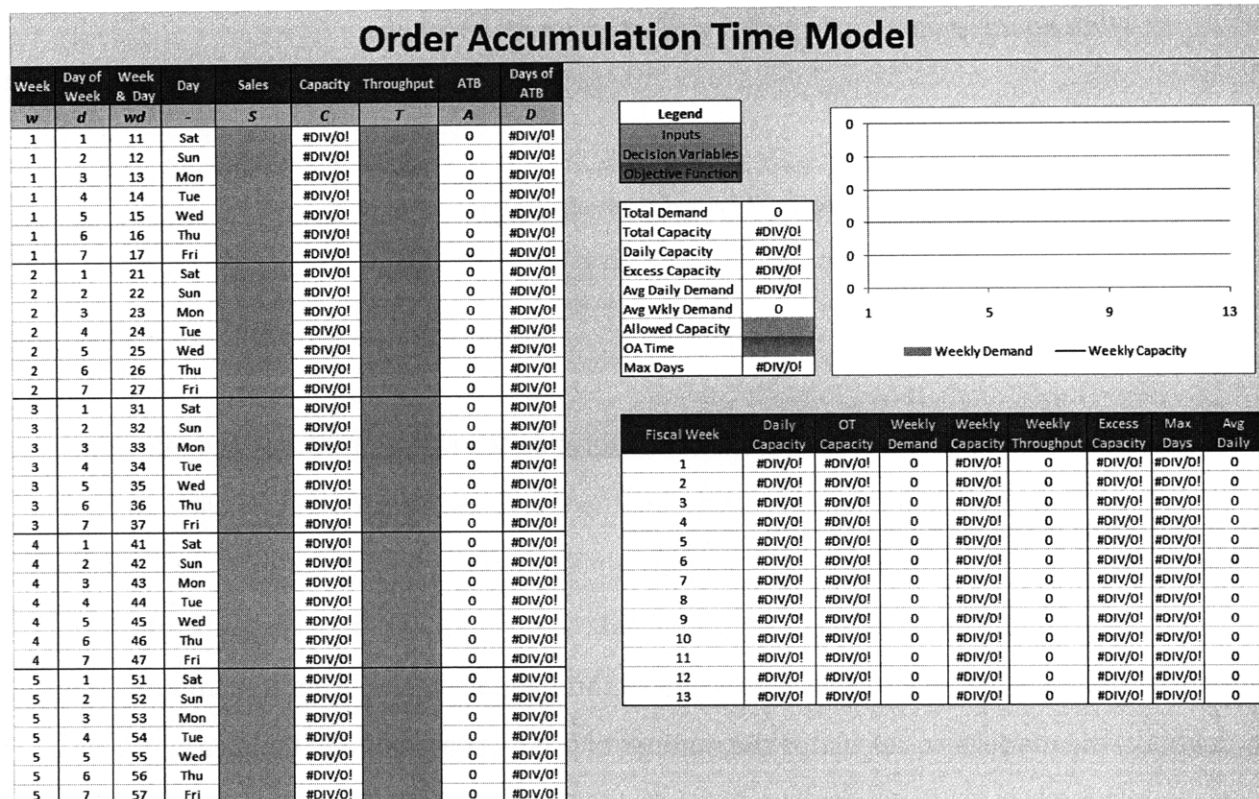


Figure 22: Order Accumulation Time Model Excel Solver Implementation

Sales data for a given time period is input into the excel model. The user will also need to input the Allowed Factory Capacity, expressed as a percentage of average daily demand during the period. Solver will then compute the factory throughput for each day based and find the optimal Order Accumulation time required to fulfill the given set of orders. The user can vary the allows capacity to determine the optimal Order Accumulation time for different factory sizes.

4.2.5 Model Example

As an illustration, the Excel model will be run for a set of orders to determine the lead-time necessary for a given set of orders. The representative sales data shown in Figure 16 is used in this example as well. The sales are fairly steady each week throughout the quarter, increasing towards the end of the quarter. Allowed Factory Capacity (k) is set to 150% in this example. Average daily sales (demand) is 33,056 units over the 13 week period. Therefore available factory capacity is 49,584 units per day. By running Solver, it was determined that for the given set of orders, a minimum Order Accumulation time of 3.02 days could be achieved with the available factory capacity. Referring back to Figures 7 and 8, this translates into a minimum order cycle time of $[11 + 3.02]$ days for the Direct Channel or $[19 + 3.02]$ days for the Retail Channel. If this cycle time will not meet the required lead time, Dell will need to add additional capacity to fulfill these orders. The figure below shows the Excel model with inputs and outputs as used in the example.

Order Accumulation Time Model

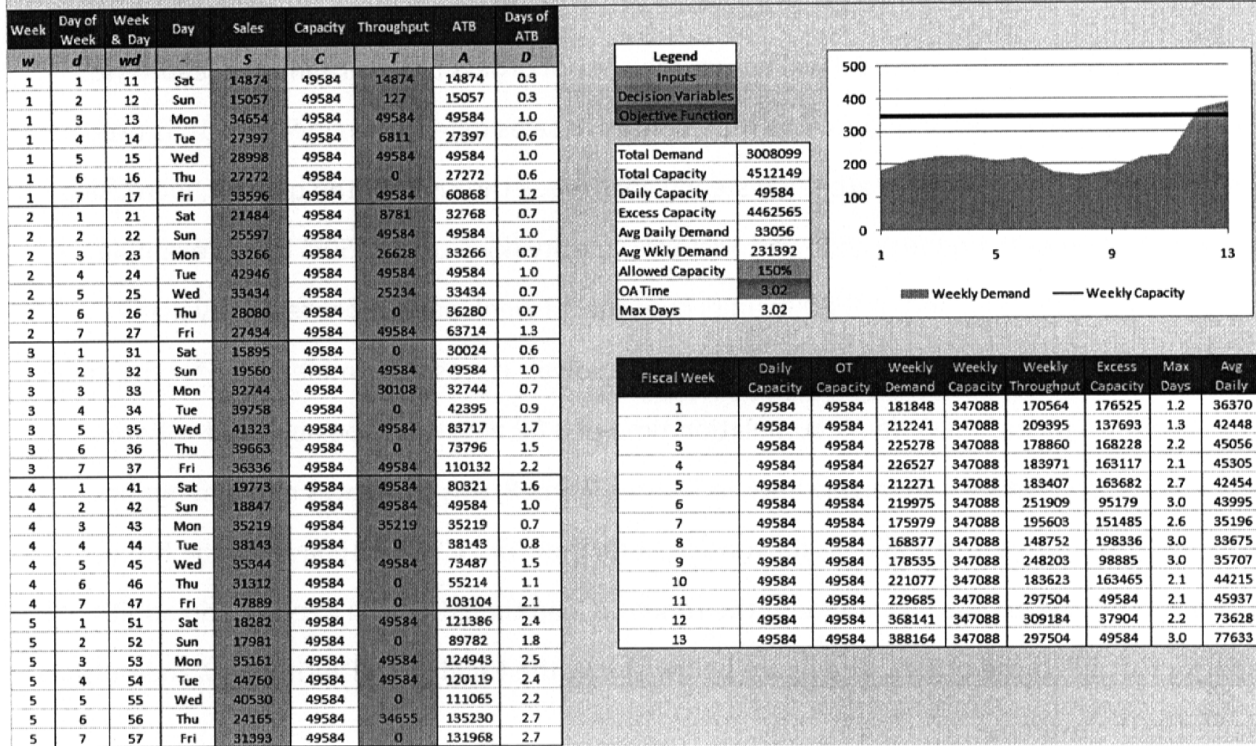


Figure 23: Order Accumulation Time Model Example

5 Findings and Discussion

This section of the thesis will focus on the analysis of results from the linear models.

5.1 Description of Findings

The linear models developed allowed Dell to examine the implications of retail sales on factory capacity. Based on historical sales patterns and current published cycle-time, a comparison can be made of the factory capacity required for the retail channel versus the traditional direct channel. In addition, the implications of potential platform disaggregation with ODM can be quantified. The primary findings of this analysis are as follows:

1. Retail orders require greater factory capacity investment than direct orders for a given order accumulation time.
2. Factory capacity investment does not decrease in a linear manner in either channel with increasing order accumulation times.
3. Platform disaggregation with ODM will increase required factory capacity compared to Dell's current manufacturing facility.

These findings are discussed in greater detail in the following sections.

5.1.1 Retail Capacity

The analysis in this section offers a comparison of required capacity in the Retail channel with the Direct channel. The analysis attempts to develop a relationship between factory capacity and order accumulation time for both the channels and performs sensitivity analysis to understand which of the variables more directly affect supply chain costs. Both the linear models were used to aid this comparison. The goal of this analysis is to evaluate whether any changes will be required to Dell's supply chain to account for the very different order pattern in retail versus the direct channel as discussed in Chapter 2.2.2.

The Capacity Investment model was run to compare the capacity requirements of the Retail channel with the direct channel, with different order accumulation times. For the purpose of this comparison, historical sales data for the two channels were each run through the model for order accumulation times of 1 to 14 days. Based on other components of order cycle times, this translated into retail cycle times between 20 and 33 days and direct cycle times of 12 to 25 days. The data used for comparison was for US consumer notebook sales over a 13 week period. The total volume of notebooks sold in each channel during this period was almost equal. For each value of order accumulation time, the level of factory capacity investment required was recorded. A sample of some of the data points captured are shown in the figures below for both the direct and retail channels. The graphs illustrate the required factory investment level in comparison with weekly sales. For low order accumulation times, the required capacity is greater than the peak demand in any week during the period. As order accumulation time increases, required capacity decreases.

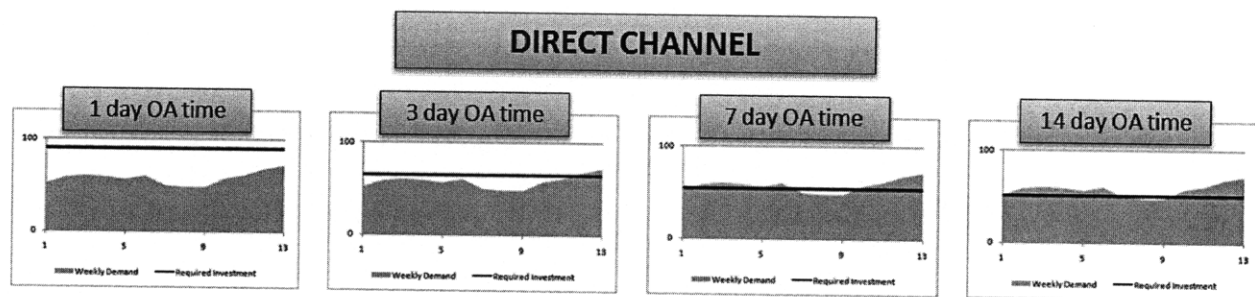


Figure 24: Direct Channel Sample Results for Required Capacity Investment

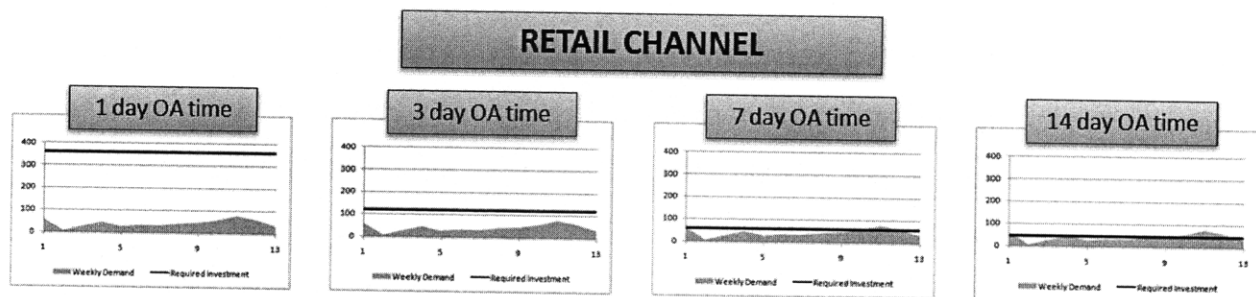


Figure 25: Retail Channel Sample Results for Required Capacity Investment

For the basis of comparison, it was decided to compare the factory capacity required as a multiple of demand in each channel. This is defined as “relative capacity”. This comparison takes into account scenarios where the volume of sales in each channel could be very different. This will give us insight into how much capacity will be required in each channel depending on the projected demand and target order accumulation time. The table below shows a direct comparison of relative capacity required in the direct and retail channels based on historical sales data.

Required Capacity as Multiple of Demand		
OA Time (days)	Direct	Retail
1	1.56	8.54
2	1.20	4.27
3	1.12	2.85
4	1.06	2.13
5	1.01	1.71
6	0.98	1.46
7	0.95	1.39
8	0.94	1.33
9	0.93	1.28
10	0.92	1.22
11	0.91	1.18
12	0.90	1.15
13	0.89	1.11
14	0.88	1.08

Table 5: Direct vs. Retail Channel Capacity Requirements

The graph below illustrates the results in the table above. The greater daily variability of orders in the retail channel due to batching, translate directly into a much greater need for capacity than in the direct channel.

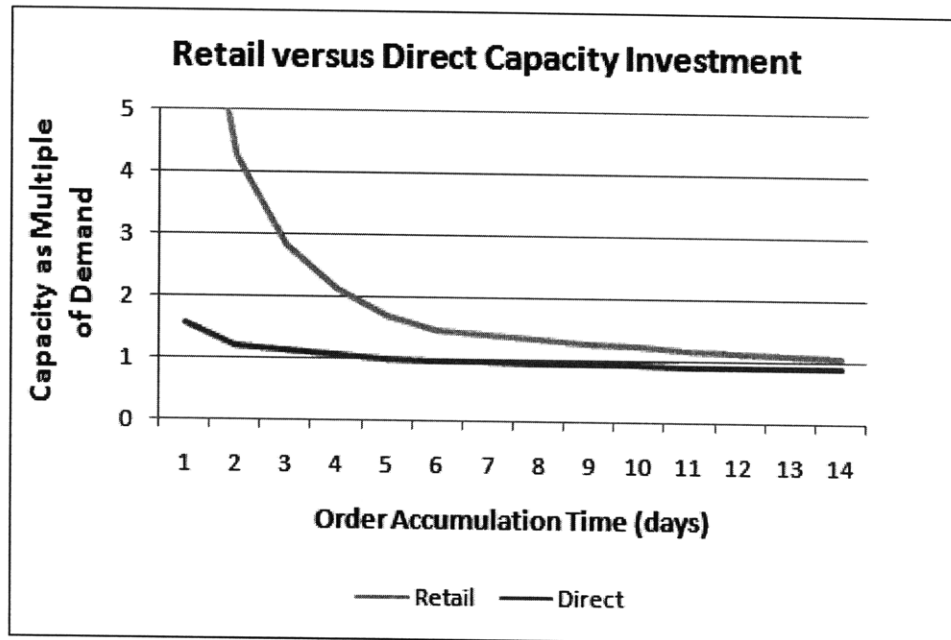


Figure 26: Direct vs. Retail Channel Capacity Investment

After analyzing current cycle-time information in both the channels, it was found that Dell currently required 77% additional factory capacity in the retail channel over the direct channel for the same volumes. The longer cycle-times in the retail channel were not enough to compensate for the much greater daily variability of retail sales. From the graph, it is clear that there is a tradeoff between the required factory capacity and order accumulation time. The nature of this relationship depends on the daily pattern and variability of the orders.

In the direct channel, the breakpoint is around 2 days order accumulation time. The relationship is close to linear for an order accumulation time greater than 1 day. There is a large tradeoff to be made to achieve order accumulation times of 1 day. This would require more than twice the capacity required to meet an order accumulation time of 2 days.

In the retail channel, there is a different tradeoff between required capacity and order accumulation time. There is a breakpoint at around 6 days. There is close to a linear relationship for order accumulation time greater than 6 days. Here, there is a linear tradeoff between lowering capacity and increasing order accumulation times. For order accumulation

times less than 6 days, there is a very different tradeoff. Factory capacity requirements increase sharply as order accumulation time is lowered. These findings can have a large effect on Dell's future supply chain design and will be key to recommendations made in the next chapter.

The Order Accumulation Time Model was also run for the same sales data as above, to offer a different comparison between the retail and direct channels. In this case the available factory capacity was varied from 100% of demand to 200% of demand (and a few other values), and the necessary order accumulation time was determined for both the retail and direct channels. The results are shown in the table below.

Order Accumulation Time (days)		
Capacity % of Demand	CTO NB	Retail NB
100%	5.36	16.93
110%	3.23	13.39
120%	2.04	10.52
130%	1.41	8.55
140%	1.14	6.87
150%	1.04	5.69
160%	0.97	5.34
170%	0.92	5.02
180%	0.87	4.74
190%	0.82	4.49
200%	0.78	4.27

300%	0.52	2.85
400%	0.39	2.13
500%	0.31	1.71

Table 6: Direct versus Retail Order Accumulation Time

The results corroborate the findings from the Capacity Investment Model. Retail orders require longer order accumulation times than direct orders with comparable factory capacity. The graph below illustrates the relationship between order accumulation time and factory capacity

for both the retail and direct channels. Once again, this is not a linear relationship in both channels, but the added order variability in the retail channel make it a much more costly proposition to reduce order accumulation time than in the direct channel.

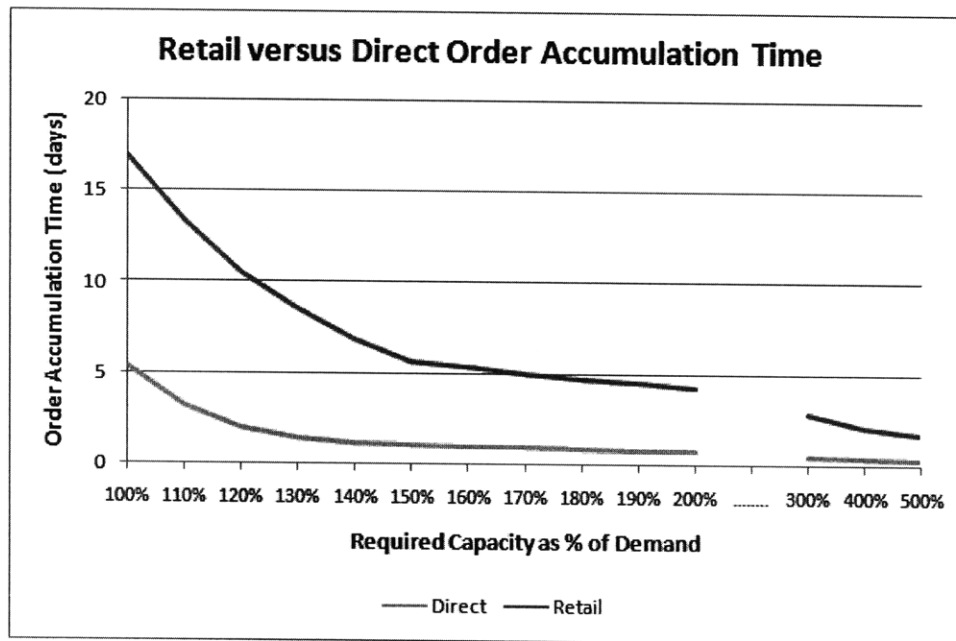


Figure 27: Direct versus Retail Order Accumulation Time

5.1.2 ODM Capacity

The analysis in this section offers an evaluation of the potential effects of platform disaggregation with ODM. As discussed in Chapter 2.2, the two major concerns with demand disaggregation were the increase in capacity needs due to the loss of level-loading different platforms and the deterioration of forecast accuracy at a platform level. These are discussed below.

As described in Chapter 5.1.1.2, the Capacity Investment Model was used to compare capacity requirements for one Dell factory manufacturing all notebooks versus five ODM factories building separate notebook platforms. The results of this example comparison discussed in chapter 5.1.1.2 are shown in the table below. The number of ODM factories and the assigning of factories can be changed and examined in a variety of combinations in the model.

OA Time	Required Factory Capacity		
	1 Factory	5 Factories	% Additional
1	182	279	53%
2	91	140	53%
3	61	93	53%
4	52	71	36%
5	50	61	23%
6	47	55	17%
7	45	51	12%
8	44	48	9%
9	43	46	8%
10	41	45	8%
11	40	44	8%
12	39	43	8%
13	38	42	9%
14	38	41	8%

Figure 28: Capacity Investment with Demand Disaggregation in ODM

Disaggregating demand into five factories, as expected, requires more capacity than a single factory, simply because the demand for each platform is not perfectly positively correlated. This comparison is made assuming 100% forecast accuracy and is a best case estimate of how much additional capacity will be required as a result of disaggregating demand by platform.

Therefore, per the model, Dell would require 53% additional factory capacity if it decided to disaggregate notebook production into five ODM factories, while maintaining order accumulation times of 1, 2 or 3 days. The capacity requirements decrease as order accumulation time increases. The graph below illustrates the comparable factory capacity requirements in the two cases.

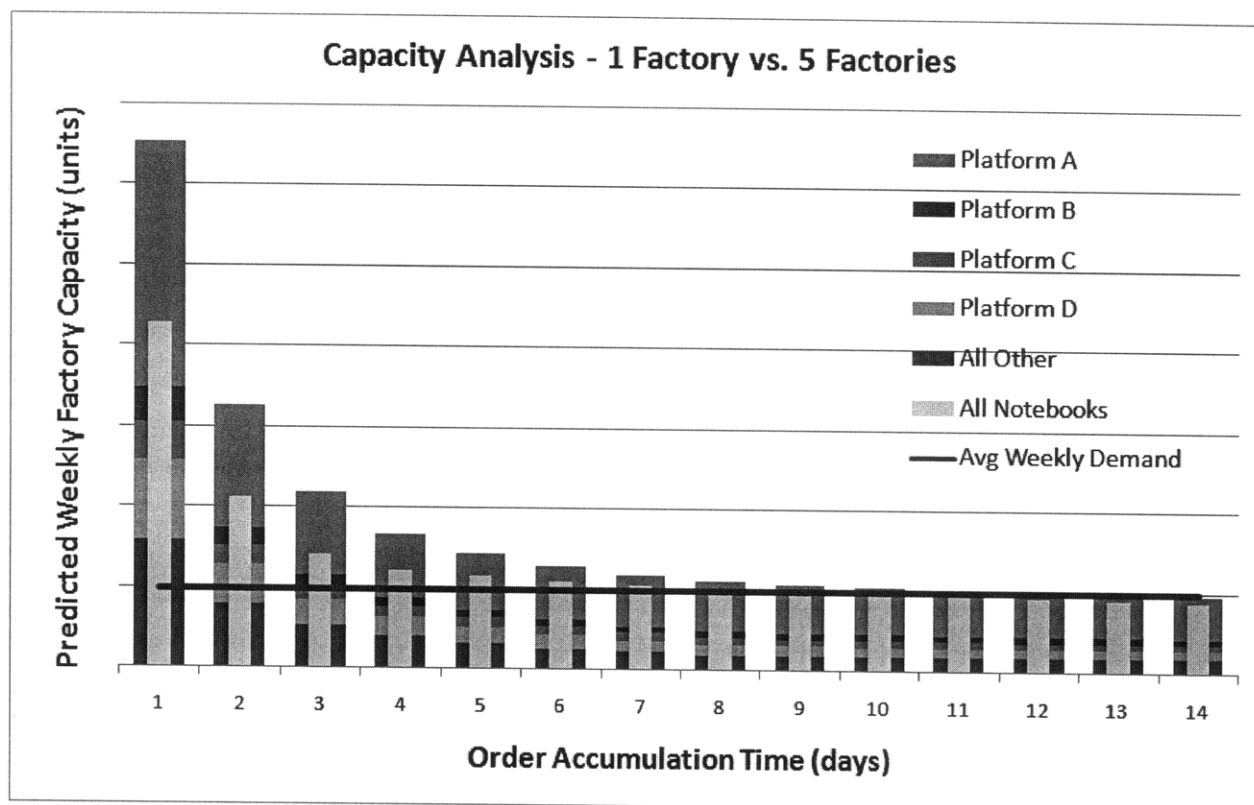


Figure 29: Capacity Requirements with Demand Disaggregation in ODM

These findings can have major implications on Dell's future supply chain design as the company evaluates a transition to Original Design Manufacturers. Unless careful consideration is given to platform level manufacturing locations, additional capacity could be required.

The above analysis assumed that forecast accuracy was 100% in both cases. However, an examination of historical data shows that there can be a significant worsening of forecast accuracy at a platform level compared to at an aggregate level. The figure below offers a comparison of forecast accuracy for each platform with that for all notebook platforms sold in the US.

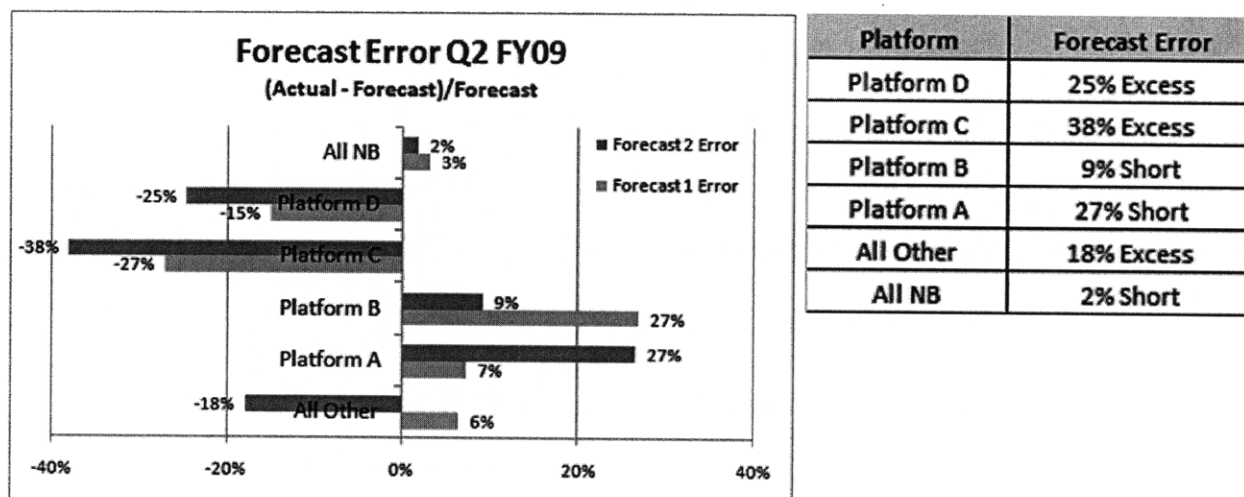


Figure 30: Forecast Accuracy with Demand Disaggregation in ODM

The forecast is much more accurate at an aggregate level than for each individual platform. Platform A sales were 27% higher than forecast, but platform D sales were 25% lower than forecast. If these two platforms were built in separate factories, there would be no risk pooling and one factory would stand idle whereas the other factory would be short on capacity and need to run overtime. If both platforms were manufactured in the same factory, forecast accuracy matters more at an aggregate level. From historical data, the aggregate forecast accuracy for notebooks is in the low single-digit range, a tremendous improvement over the platform level forecasts. Depending on the forecast accuracy for each platform, there can be a significant increase in required factory capacity through disaggregation because of the lower forecast accuracy. In the data collected, this can be anywhere between 10% and 20% of total capacity.

This analysis demonstrates the need for additional capacity if production is disaggregated into multiple factories by platform. The cumulative impact of the platform loading and forecast inaccuracy can result in a need for anywhere between 40% to 60% additional capacity. This needs to be a major factor under consideration while designing a cost effective supply chain.

5.2 Recommendations

Dell will need to tread carefully while redesigning its supply chain to better serve the retail channel. They will also need to consider the effects of demand disaggregation as they transfer some PC manufacturing capacity to ODM partners. This section discusses some specific recommendations regarding supply chain design based on the analysis above.

1. Dell should *increase retail channel lead-times* in order to minimize the need for additional manufacturing capacity. The analysis illustrates that the high daily volume variability of retail orders result in a greater requirement for factory capacity than orders through the direct channel. Rather than attempt to reduce the large order size in retail to match the direct channel, it is advised to increase the average lead-time offered to the retailers. Alternatively, Dell could also attempt to reduce its internal cycle-time for retail orders, but it is believed that any improvement in this process would require a substantial investment in internal IT infrastructure. Reducing internal cycle-times is a valid long-term solution, but is not viable in the short-term. Additionally, competitive analysis suggests that other PC vendors offer much longer lead-times to retailers compared to Dell. Increasing lead-times offered to retailers by 1 week would greatly reduce the required manufacturing capacity for retail orders, while maintaining a shorter lead time than the competition.
2. Dell should *reconsider accepting large volumes of Burst requests* from retailers when factory capacity is not available. Currently, Dell has been successful in providing retailers with mid-cycle requests for PC's in large volumes at shortened lead-times. These are called *Burst* orders and are generally to fill an unmet immediate need in the marketplace. While the ability to fulfill these orders has won Dell more sales, in some cases the factories have not had the capacity to meet the required demand. This results in overtime, delaying of other orders and expediting of shipments to meet the deadline. It is recommended that Dell only accept these orders when factory capacity is available, since the alternative has major consequences on the supply chain.

3. Dell should *minimize the number of ODMs* it partners with to manufacture notebooks to reduce the impact of demand disaggregation. The analysis in this thesis demonstrates the negative impact of disaggregating notebook demand into multiple factories compared to a single factory. The same applies for other products including desktops, servers, monitors, etc. There are several reasons to disaggregate demand into multiple factories including risk mitigation, locating close to the customer to reduce lead-time and logistics costs or existing manufacturing infrastructure. However, these concerns should be balanced with an understanding that aggregating demand will reduce overall costs by reducing capacity requirements and reducing a dependency on demand forecasts. Dell should consider the correlation between the demand of various products and try and assign products to factories so that the overall demand in each factory is close to perfectly positively correlated. This can be done by examining historical demand for product families. In general, Dell should minimize its ODM partnerships to mitigate this problem to some extent.

5.3 Conclusion

Dell's decision to sell PC's through the retail channel represents a major change to its famous Direct model. In order to improve its effectiveness in the retail channel, Dell will need to adjust its current build-to-order supply chain and understand the tradeoff between order variability, order lead time and factory capacity. Knowing the order variability of retail, Dell can determine the optimal lead time for retail orders so that it does not have to significantly increase its investment in manufacturing capacity. The result of these findings are true for any industry when the pattern of demand changes due to external factors.

Additionally, Dell's transition to more outsourced manufacturing puts it in line with most of its competitors and follows a trend across many industries. The thesis demonstrates that one aspect of ODM implementation – demand disaggregation – can have a major impact on manufacturing capacity. This is often an aspect that is overlooked, given the many challenges a transition to ODM involves.

Bibliography

- Anupindi, R., Chopra, S., Deshmukh, S., Van Mieghem, J., & Zemel, E. *Managing Business Process Flows* (Second Edition ed.). Pearson Prentice Hall.
- Beckman, S., & Rosenfield, D. *Operations Strategy*. McGraw Hill.
- Carroll, J. S. (2006, June). Introduction to Organizational Analysis: The Three Lenses. *Dell Corporate Website*. (n.d.). Retrieved 24, 2009, from <http://www.dell.com>
- Dhalla, N. (2008). *Evaluating Shortage Costs in a Dynamic Environment*. MIT.
- Hoovers. (n.d.). Retrieved 24, 2009, from <http://www.hoovers.com>
- Kraemer, K., & Dedrick, J. (2007). *Market Making in the PC Industry*.
- Ngain, E., & Gunasekaran, A. (2005). Build-to-order supply chain management: a literature review and framework for development. *Journal of Operations Management* , 423-451.
- Silver, E., Pyke, D., & Peterson, R. *Inventory Management and Production Planning and Scheduling* (Third Edition ed.). John Wiley & Sons.
- Spera, C., & Ghiassi, M. (2003). Defining the Internet-based supply chain system for mass customized markets. *Computers and Industrial Engineering* , 17-41.

Appendix A Glossary

ATB	Available to Build – The number of orders in a factory that have all required parts available to start build
BTO	Build-to-Order
Burst SKU's	Configurations sold midway through a retail buying cycle with shortened lead times to meet an immediate market need
CM	Contract Manufacturer – A firm that manufactures components or products for another "hiring" firm, typically an OEM
DAO	Dell Americas Operations – Includes operations in North, Central and South America
IP	In Production – On Dell's order timeline, IP indicates that the customer order payment has been processed and is ready for build
JIT	Just-in-Time
MABD	Must Arrive By Date – The date by which the order must be delivered to the retailer
MPP	Master Production Plan – Production Forecast by LOB and Platform
MRP	Material Resource Plan – Material Procurement Forecast by Part
MSP	Master Sales Plan – Sales forecast by LOB and Platform
OA time	Order Accumulation time – Manufacturing buffer time available between OE and TP
ODM	Original Design Manufacturer – A company which designs and manufactures a product which ultimately will be branded by another firm for sale
OE	Order Entry – this is the date when the customer places the order
OEM	Original Equipment Manufacturer – A company that uses a component made by a second company in its own product, or sells the product of the second company under its own brand
PC	Personal Computer
Platform	Refers to a specific product model or brand
POR	Plan Of Record – Sales Plan for retail buying cycle. Contains configuration, pricing and volume information for each retailer
SC	Ship Complete – the date that the customer order is shipped
TP	Traveler Pull – on Dell's order timeline, this is when all parts become available to build the order (once the order payment has been authorized)